TRAFFICABILITY TESTS WITH THE MARSH SCREW AMPHIBIAN ON COARSE-GRAINED AND FINE-GRAINED SOILS

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PREFACE

The trafficability tests with the Marsh Screw Amphibian reported herein were requested by the Advanced Research Projects Agency (ARPA) in a letter to U. S. Army Materiel Command dated 9 August 1963. Funds were provided under ARPA order No. 400, amendment No. 4. The tests were conducted at four sites within a 20-mile radius of Vicksburg, Miss., during the period 22 August-23 October 1963 by personnel of the U. S. Army Engineer Waterways Experiment Station, Army Mobility Research Branch, under the general supervision of Messrs. W. J. Turnbull, Technical Assistant for Soils and Environmental Engineering; W. G. Shockley, Chief of the Mobility and Environmental Division; S. J. Knight, Chief of the Army Mobility Research Branch; and E. S. Rush, Acting Chief of the Trafficability Section. Messrs. A. B. Thompson and B. G. Stinson of the Trafficability Section supervised the field testing. This report was prepared by Messrs. Knight, Rush, and Stinson. This program was conducted under the sponsorship and guidance of the Directorate of Research and Development, U. S. Army Materiel Command.

Acknowledgment is made to the Office of Naval Research for its part in making the Marsh Screw available and to personnel of Chrysler Corporation Defense Engineering, builders of the Marsh Screw, for assistance and support during the tests.

Col. Alex G. Sutton, Jr., CE, was Director of the Waterways Experiment Station during the testing program and preparation of this report. Mr. J. B. Tiffany was Technical Director.

CONTENTS

SUMMARY

The Marsh Screw Amphibian is of interest in the Army's mobility research program because of its unusual concept of locomotion which is based on the Archimedean screw. It moves by means of two counterrotating rotors which give forward and backward thrust to the vehicle. When both rotors are made to turn in the same direction, the vehicle will move laterally; however, there is no provision for steering when the vehicle is moving laterally.

Trafficability tests with the Marsh Screw were performed to determine its performance on three soil types: sand, clay, and silt. Repetitive-pass tests and speed tests were conducted on clay and sand; towing tests on clay, silt, and sand; slope-climbing tests on sand; and obstacle tests on silt. For comparison, tests with an M29C weasel were conducted and performance curves from previous test programs were utilized. Test results indicate that:

- a. On sand the Marsh Screw, unloaded, could travel although progress was labored and speed was slow; loaded, it could not travel in reverse because of a lower torque multiplication ratio in the transmission reverse gear. It could tow a reasonable load or climb a reasonable slope, but at only approximately 0.5 mph.
- b. In fine-grained soil the Marsh Screw could travel on extremely low soil strengths (lower than any vehicle previously tested) provided free water was present, but on soils with no free water present it became immobilized in soft, sticky conditions and firm conditions because of inadequate power.
- c. The Marsh Screw could travel laterally on all soil conditions except those of very low strengths, but could not be steered.
- d. Obstacle crossing ability of the Marsh Screw on simulated rice-field dikes was poor because of its unsprung suspension system.

Appendix A presents a detailed description of the determination of mobility indexes and vehicle cone index for the Marsh Screw. Appendix B discusses the power train system.

TRAFFICABILITY TESTS WITH THE MARSH SCREW AMPHIBIAN ON COARSE-GRAINED AND FINE-GRAINED SOILS

PART I: BACKGROUND, PURPOSE, AND SCOPE

Background

1. The Marsh Screw Amphibian is an experimental vehicle designed to operate in marshy soils and water. Its unusual propulsion system, consisting of two threaded pontoons, has never before been incorporated into a full-size, working vehicle. Two counterrotating rotors give forward and backward thrust to the vehicle, and when both rotors turn in the same direction, the vehicle will move laterally. However, there is no provision for steering when the vehicle is moving laterally. The vehicle was designed and built by Chrysler Corporation Defense Engineering for the Bureau of Ships, Department of the Navy, under contract No. NObs 4558, Code 529V. Requirements for the vehicle and funds for its development originated at the Advanced Research Projects Agency (ARPA).

2. The Marsh Screw Amphibian was subjected by its builders to considerable testing on water, marshland, tidal mud flats, sand, and snow, and in some cases, up slopes and across ditches. The tests showed the vehicle to have good performance characteristics in water, marshland, tidal mud flats, and snow, but low performance levels in sand and firm, dry, fine-grained soils.

3. Since quantitative measurements of terrain conditions were not made in the Chrysler testing program, it was impracticable to compare directly the Marsh Screw's performance with that of other vehicles on similar terrain conditions. Accordingly, the U. S. Navy Bureau of Ships requested the Waterways Experiment Station (WES) to undertake a limited program of testing with the Marsh Screw on soil conditions occurring near Vicksburg, Miss. Because of the vehicle's unusual method of propulsion, the Marsh Screw was of interest to the WES in connection with its mobility research program.

Purpose

4. The primary purpose of the test program was to determine quantitatively the performance of the Marsh Screw Amphibian in soft soils. Of particular importance was the determination of the minimum soil strength required for the vehicle to propel itself (vehicle cone index, VCI). Other measures of vehicle performance investigated were towing force, slip, speed, maneuverability, and slope-climbing ability. Soil and terrain parameters measured were strength, moisture content, slope, and vegetation. Establishment of these quantitative vehicle-soil-terrain relations will facilitate comparison of the Marsh Screw's performance with that of the many military wheeled and tracked vehicles that have been tested by the WES.

Scope

5. Tests were conducted with the Marsh Screw at two different weights, on three soil types ranging from heavy clay to fine sand, in the vicinity of Vicksburg, Miss., during the period 22 August-23 October 1963. Twelve tests with an M29C weasel also were conducted for comparative purposes.

6. The scope of the program was limited by the soil conditions that prevailed during the test period. The program, therefore, should not be considered as an exhaustive testing of the Marsh Screw.

PART II: DESCRIPTION OF THE MARSH SCREW AMPHIBIAN

7. The Marsh Screw's unusual concept of locomotion places it outside the normal tracked and wheeled vehicle classifications. "The vehicle's name is the best possible, three-word description. Marsh is the area in which it is designed to operate and the area [in] which it performs best. The word Screw describes the method of propulsion, which is based on the Archimedean screw, two of which are used. Amphibian is the general vehicle classification because the vehicle will run on water, marsh, and on many land conditions."* Features of the vehicle are shown in figs. 1 and 2.

Fig. 1. Marsh Screw Amphibian (front view)

Fig. 2. Marsh Screw Amphibian (side view)

* Chrysler Corporation Defense Engineering, Marsh Screw Amphibian, Test Report (July 1963).

Vehicle Characteristics

8. Pertinent data on the model of the Marsh Screw tested are as follows:

<u>General</u>

Empty weight, lb (as tested)(includes driver and fuel)	2860
Loaded weight, lb (includes driver, fuel, and a 1094-lb payload)	3954
Ground pressure (at 3-in. penetration) empty, psi	0.52
Ground pressure (at 3-in. penetration) loaded, psi	0.72
Computed VCI* (2860 lb)	8
Computed VCI (3954 lb)	11

<u>Dimensions</u>

Length, overall, ft	13.66
Width, overall, ft	8.16
Height, overall, ft	4.75
Rotor spacing (center to center), in.	66
Rotor diameter (drum only), in.	26
Rotor diameter (over helix),** in.	31
Rotor length (overall), in.	152
Rotor length (in contact with ground, no rut), in.	129.5
Ground clearance, in.	20

<u>Engine</u>

Make	Chrysler
Model	RG Special
Type	Spark ignition, slant 6 cyl, water cooled, OHV
Bore and stroke	3.40 x 4.25 in.
Displacement	225 cu in.
Governed speed	3600 rpm
Net horsepower, brake	116 at 3600 rpm

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* See Appendix A for definition and computation of VCI. For definitions of trafficability terms see WES Technical Memorandum No. 3-240, 14th Supplement, <u>Trafficability of Soils; A summary of Trafficability Studies Through 1955</u> (Vicksburg, Miss., December 1956).

** When built, helixes were 3 in. wide; however, at beginning of test program they were worn to approximately 2.5 in.

Power train

Transmission: Chrysler torqueflite model A-727, 3-speed transmission with electric clutch/brake controlled by a steering wheel through a chain-driven, double-reduction final drive, ratio 6.55:1.

Electrical system

12-volt/w alternator

Materials

Body and rotors	6061 T6 aluminum
Engine block	Aluminum
Transmission housing	Aluminum
Final drive housing	Aluminum

Propulsion System

Tractive elements

9. The principle of propulsion of the Marsh Screw is the worm (Archimedes screw). The vehicle travels on two tapered-end cylinders or rotors. Each rotor is filled with polyurethane foam to prevent entry of water in case of puncture of the thin metal skin. The ends of the rotors are truncated to provide a flat section for attaching hull supports. Two helical blades are welded to each rotor in a continuous pattern from front to rear. The lead of the helix (the distance the inclined helix travels in one complete circle around the rotor) is 48 in., and the helix angle is approximately 32 degrees with the vertical. The rotors are counterrotated to give forward or backward thrust to the vehicle. Turning is accomplished by reducing power and applying brakes to one rotor while applying power to the other. When both rotors are made to turn in the same direction, the vehicle will move laterally; however, there is no provision for steering the vehicle while it is moving laterally.

Power train

10. Power is transmitted from the engine through a torque converter and transmission system to a final chain drive connected to each rotor.*

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* For discussion and computations, see Appendix B.

Driver's Observations of Vehicle Performance

11. One driver, a man with more than 20 years experience as a vehicle operator and mechanic, operated the Marsh Screw Amphibian throughout the entire test program. During the course of the tests, the driver made the following qualitative observations on vehicle performance:

a. When the engine was operating at greater than 1500 rpm, there was no overheating. When the engine was operating at less than 1500 rpm, overheating usually occurred.

b. In periods of engine overheating, the torque converter fluid also became heated. The thinner, heated fluid apparently caused a net reduction of power to the rotors.

c. During the test program the vehicle could sometimes tow an appreciable load in the same soil condition in which it was barely able to propel itself. The driver's observation was that the engine efficiency was higher during the towing tests because the engine had time to cool between tests (while personnel examined recorder tapes, etc.) whereas during other tests the vehicle often operated with a hotter engine.

d. The vehicle did not have enough power to propel itself forward at low gear in firm, dry soils.

e. The steering mechanism was not very effective in maneuvering the vehicle.

f. The vehicle appeared to travel with less strain in forward gear than in reverse gear, especially when deep rutting was occurring.

PART III: TEST PROGRAM

Location and Description of Test Areas

12. The test areas were located on a Mississippi River beach and at Albemarle Lake, Centennial Lake, and the WES. All test areas were within a 20-mile radius of Vicksburg, Miss. (see plate 1).

Mississippi River beach

13. This area, located approximately 5 miles south of Vicksburg on the west bank of the Mississippi River, was a gently undulating beach with an average slope of about 1 to 6% along the foreshore. A series of flat terraces of dry, soft sand, classified as uniform fine sand (SP), occurred inland from the water's edge. Some of the terraces were partially stabilized by vegetation while others were barren. Fig. 3 shows a general view of the test area.

Fig. 3. Mississippi River beach test area

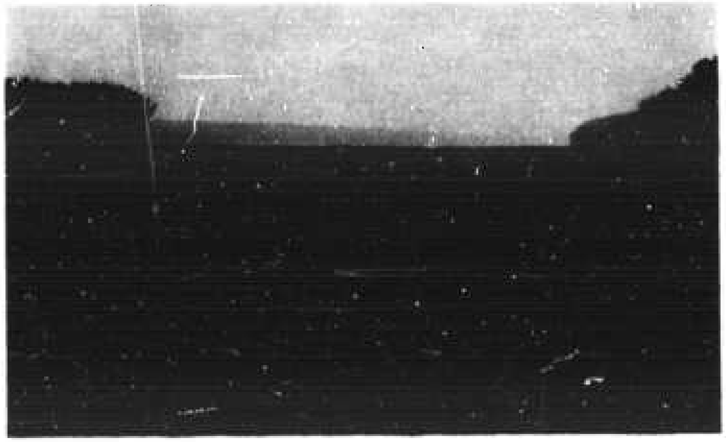


Fig. 4. Albemarle Lake test area

Albemarle Lake

14. Albemarle Lake, about 16 miles northwest of Vicksburg, lies in an old channel of the Mississippi River and is still connected to the present river; therefore, the lake level fluctuates as the Mississippi River rises and falls. Tests were conducted on the fairly flat perimeter of the lake during a period of low-water level (see fig. 4). Most of the

area was covered with grass 2 to 5 ft tall; however, areas near the water's edge were devoid of vegetation. The soil in the area classified as fat clay (CH). A progressive decrease in moisture content with distance from the water's edge permitted testing on a wide range of soil moisture and strength conditions.

Fig. 5. Centennial Lake test area

Centennial Lake

15. Centennial Lake, located approximately 1 mile west of Vicksburg, is also situated in an old channel of the Mississippi River and is connected to the Yazoo Diversion Canal which flows into the Mississippi River. The test area was located on the Louisiana side of the Yazoo Diversion Canal, on the perimeter of the nearly level lake bed (see fig. 5). The tests were conducted during a low-water period. Vegetation in the area consisted of willow trees 2 to 5 ft in height. Areas near the water's edge were barren. The soil at this test area classified as fat clay (CH).

WES reservation

16. Tests at the WES were conducted in three different areas, on bottomland silt and buckshot clay soils. These areas are described in the following paragraphs.

17. Simulated rice field. Fig. 6 shows a

Fig. 6. Simulated rice-field test area

simulated rice field with four dikes of varying dimensions in a bottomland silt (ML) area. Spaces between the dikes were flooded with water to a depth of approximately 8 in. The dikes were stabilized with cement so that they would retain their shapes after water was applied. The cone index of the soil in the dikes was greater than 300.

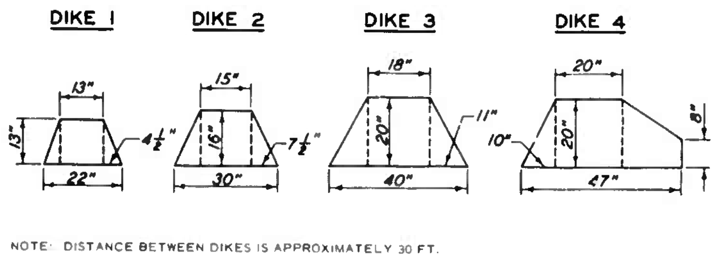


Fig. 7. Cross section of simulated rice field, WES test area

Fig. 7 shows a cross section of the simulated rice field.

18. Prepared buckshot clay test lane. This test lane was constructed on a stockpile of fat clay (CH) soil, locally called "buckshot" clay. The area was smoothed and compacted while dry, then approximately 6 in. of loose, dry material was placed on the surface. The surface was wetted by intermittent sprinkling for a two-day period prior to testing. Fig. 8 shows a view of the test area.

Fig. 8. Prepared buckshot clay, WES test area

19. Natural bottomland silt. Fig. 9 shows a view of a test area of natural

Fig. 9. Natural bottomland silt, WES test area

bottomland silt (ML), partially covered with dry, brown grass 1 to 2-1/2 ft high underlain by a mat of green grass.

Soils Tested

20. Gradation curves, Atterberg limits, and Unified Soil Classification System designations for the soils tested are given in plates 2-5. Moisture contents and densities for specific tests are contained in tables 1-6.

Tests Conducted

21. Three general types of tests, referred to in this report as self-propelled, towing, and towed-vehicle, were conducted with the Marsh Screw Amphibian. The total number of tests conducted with this vehicle was 124. Four self-propelled and eight towing tests were conducted with an M29C weasel for comparative purposes. The following tabulation shows the number of tests of each type conducted at each test area.

	Tests with Marsh Screw Amphibian					Tests with Weasel		
		Heavy Clay (CH)				Heavy Clay (CH)		
Test Type	Sand (SP) Mississippi River	Albemarle Lake	Centennial Lake	Prepared Buckshot Clay	Bottomland Silt (ML) WES	Albemarle Lake	Centennial Lake	Bottomland Silt (ML) WES
Self-propelled								
Repetitive-pass	4(1A)	11(2A)	6(3A)	1(5)	0	2(6A)	1(6A)	0
Straight-line speed	2(1B)	3(2C)	0	0	0	0	0	0
Maneuver-speed	2*	3(2D)	0	0	0	0	0	0
Slope-climbing	16(1C)	0	0	0	0	0	0	0
Obstacle	0	0	0	0	2(4B)	0	0	1(4B)
Towing								
Towing force-slip	16**(1D)	7(2B)	20**(3B)	0	0	0	8(6B)	0
Maximum towing force								
Forward	2(1D)	21(2B)	13(3B)	0	2(4A)	0	0	0
Lateral	0	3(2B)	3(3B)	0	0	0	0	0
Towed-vehicle								
Forward	0	1*	0	0	0	0	0	0
Lateral	0	1*	0	0	0	0	0	0
Total	40	50	29	1	4	2	9	1

Note: Numbers in parentheses denote the tables in which data are presented.
* Tests attempted; data not included in tables 1-6.
** Maximum towing force tests (forward) are included in this number.

Test Procedures and Data Collected

Self-propelled tests

22. In a self-propelled test the vehicle travels alone; that is, it tows no trailer or other attachment. Five kinds of self-propelled tests

were conducted: repetitive-pass, straight-line speed, maneuver-speed, slope-climbing, and obstacle.

23. Repetitive-pass tests. In these tests, the vehicle usually traveled forward and then backward on level terrain a distance of 100 ft in the same straight line until it became immobilized or until it completed 50 passes. Any deviation from this pattern is noted in the text and data tables. Vehicle speed was maintained at approximately 1 to 2 mph, except where noted in the text and tables.

24. In clay soils, test lanes 100 ft long were staked off and the cone index of the soil was measured, usually at 10-ft intervals along the center line of the proposed path of each rotor, at the surface, and at 3-in. vertical increments to a depth of 24 in., and at 30- and 36-in. depths. For the fine-grained soils at the two lake sites, two remolding tests (one in each proposed rotor path) were made on samples taken from each of the 0- to 6-in., 3- to 9-in., 6- to 12-in., 9- to 15-in., and 12- to 18-in. depths near the point where the lowest cone index was measured. Samples for moisture content and density determinations were taken from the same depths at each remolding station. (Walking was very difficult in extremely soft areas and plywood boards had to be used to support test personnel.) After these data were collected, tests with the Marsh Screw Amphibian were begun. Rut depths and cone indexes in the ruts were measured periodically during each test. Observations were recorded of the behavior of the soil and the vehicle during each test.

25. The tests in sand were conducted in a similar manner except that remolding tests were not made. Cone index measurements seldom could be obtained at depths below about 18 in. because of the firmness of the material.

26. Straight-line speed tests. Straight test lanes, approximately 400 ft in length, were used for these tests. The vehicle was accelerated to its maximum possible speed before it entered the test lane and then proceeded through the lane at its maximum speed. The time of entry into the lane was noted, and at 10-sec intervals thereafter a marker was dropped from the vehicle. This procedure was continued to the end of the lane where the time of exit was noted. Distances between markers were measured along the path of the vehicle. Soil moisture, density, and strength were measured at arbitrary distances between the markers.

27. Maneuver-speed tests. Maneuver-speed test courses were staked out parallel to those used in straight-line speed tests. Control stakes were placed in a straight line along the center line of the test course, and the vehicle was maneuvered (at maximum speed) between the stakes by going to the left of the first stake, to the right of the second stake, and so on through the lane. Distances between control stakes were 30 ft for some lanes and 50 ft for other lanes. Time and distance data were obtained by the same procedure used for the straight-line speed tests. Increments of distance on a curved path were projected to the straight line. Soil and cone index data were taken between the 10-sec markers.

28. Slope-climbing tests. Slope-climbing tests were conducted on the Mississippi River beach. The greatest slope which the vehicle negotiated, or the slope upon which it was immobilized in a given test, was measured with an Abney level. Cone index, moisture content, and density were measured on both sides of the vehicle after the completion of the test. These measurements were made outside the zone of disturbance by the vehicle. Because of the uniformity of the sand, these data are used as before-traffic data.

29. Obstacle tests. Obstacle tests were conducted only in the simulated rice field. The vehicle was driven through the rice field as fast as considered practicable by the driver. Times of entry and exit were noted and the time required to cross each dike was also determined. Soil strength was measured in the ponds between the dikes before traffic. Three accelerometers were mounted near the front of the vehicle and three near the rear of the vehicle to measure accelerations (shocks) occurring longitudinally, laterally, and vertically at each end of the vehicle. The accelerations were measured in terms of g's (one g equals 32.16 ft/sec^2) and were recorded by an oscillograph, which was mounted in an instrument vehicle (weasel) which ran parallel to the test vehicle outside the test course.

Towing tests

30. Towing tests were of two general kinds: tests in which the maximum towing force (maximum drawbar pull) the vehicle could develop was measured; and tests in which the towing force and slip were measured for a range of towing force and slip conditions.

31. Maximum towing force tests. These tests were performed on level terrain with the Marsh Screw attached to a load vehicle (a weasel) by means of a cable and a dynamometer. As the Marsh Screw moved forward in a straight line at full throttle, the load on the Marsh Screw was gradually increased by decelerating the weasel. Continuous measurements of the pull being developed and the speed of the Marsh Screw were recorded on paper tape. Maximum pull was arbitrarily determined to be the load that could be moved by the Marsh Screw operating at full throttle and traveling at a speed of 0.5 mph or slightly greater. Higher pulls were usually obtained, but these caused the Marsh Screw to halt or to significantly decrease its speed below 0.5 mph. The area in which the maximum pull occurred was noted and soil strength, moisture, and density were measured adjacent to the area in a manner similar to that used for the repetitive-pass tests.

32. Towing force-slip tests. Towing force-slip tests were conducted in the same general manner as the maximum towing force tests except that the distance the vehicle moved forward, the number of revolutions of the rotors, and the pull developed by the vehicle were measured simultaneously. The distance the vehicle traveled was measured by means of a wheel attached to the rear of the vehicle (fig. 10), and the number of revolutions made by the rotors was measured by means of a microswitch and collar fitted on the support shaft of the rotor (fig. 11). Test procedures for obtaining

Fig. 10. Wheel for measuring distance traveled

Fig. 11. Microswitch for measuring rotor revolutions

towing force measurements were similar to those described under maximum towing force tests, except loads were varied to obtain a number of pull-slip combinations between zero slip and 100% slip.

33. When a conventional vehicle moves forward at no slip, the distance that a point on the periphery of its track (or wheel) moves in space is equal to the distance that the vehicle moves along the ground. Finite slips are computed according to the expression:

$$\% \text{ slip} = 100 \times \frac{\text{dist traveled by track or wheel - dist traveled by vehicle}}{\text{dist traveled by track or wheel}}$$

The lead of the helixes on the pontoons of the Marsh Screw is 48 in.; therefore, when the vehicle moves forward at no slip, it travels 48 in. for each complete revolution of the pontoons. When 100% slip occurs, the pontoons spin but the vehicle makes no progress. Finite slips for this vehicle were computed according to the expression:

$$\% \text{ slip} = 100 \times \frac{(48 \times \text{no. of revolutions of pontoon}) - \text{dist traveled by vehicle in inches}}{48 \times \text{no. of revolutions of pontoons}}$$

Towed-vehicle tests

34. In these tests, measurements were made of the force required to tow the Marsh Screw across level terrain. These tests are normally performed with the vehicle in neutral gear. Only limited tests were conducted since the vehicle did not respond well to being towed forward or backward. Measurements also were made of the force required to tow it laterally.

PART IV: ANALYSIS OF DATA

35. Development of comprehensive relations between soil conditions and the tractive performance of the Marsh Screw was hampered somewhat because the engine power of the vehicle was not sufficient to turn its rotors in certain soil conditions. In such conditions, immobilization was therefore primarily a result of vehicle characteristics rather than a result of soil failure. This problem has seldom been encountered with more conventional vehicles, since these can nearly always spin their tracks or wheels when they have become immobilized. If free water, especially surface water, was present, the Marsh Screw had little difficulty in traveling. However, when the surface was relatively dry and there was not enough water in the subsurface layers to be squeezed out and mixed with the surface layer, the friction created between the rotors and the soil usually was greater than could be overcome by the engine power and drive system, and the vehicle could not move forward or backward, but the vehicle could travel laterally.

Tests on Coarse-Grained Soils

36. Repetitive-pass, straight-line speed, maneuver-speed, slope-climbing, and towing tests were conducted at the Mississippi River beach area on uniform fine sand (SP). Table 1 summarizes results of these tests.

37. In previous test programs with wheeled and tracked vehicles, the 0- to 6-in. layer was established as the critical layer* in clean sand for all vehicles tested thus far; therefore, this layer was used as the basis for analysis of the Marsh Screw's performance in sand. Previous testing with wheeled and tracked vehicles also established that if a vehicle could negotiate the given sand and slope condition on the first pass, it could travel in the same ruts for any number of passes. However, since the Marsh Screw has an unusual locomotion principle it was decided to conduct repetitive-pass tests as well as slope-climbing and towing tests to determine if criteria established for other vehicles would be appropriate for the Marsh Screw.

Repetitive-pass tests

38. Four repetitive-pass tests on level sand were conducted with the

* Critical layer is defined as the layer of soil most pertinent in establishing relations between soil strength and vehicle performance.

Marsh Screw at full throttle, two with the vehicle empty (2860 lb), and two with it loaded (3954 lb). A summary of the data and results of these tests is given in table 1A.

39. In the two tests at 2860 lb (tests 39 and 57), the operator experienced difficulty in keeping the vehicle in the test lane for the first few passes; however, after ruts about 6 in. deep had been developed the vehicle had no great difficulty following the same track on each pass. The action of the unloaded Marsh Screw on level sand can be illustrated by a series of photographs made for test 39. In this test, the 0- to 6-in. cone index was 60. Fig. 12 shows the test area prior to the test. Fig. 13 shows the path left after one pass of the vehicle; the ruts are about 5.6 in. deep. The average speed on the first pass was about 1 mph. Since the vehicle was at full throttle, this may be considered a maximum speed. Considerable difficulty was experienced on the first pass in keeping the vehicle in a straight line; it was necessary for the driver to steer continuously. Finally after a series of short, abrupt steering actions, the vehicle could not continue to turn its rotors and move forward. At this point, the vehicle was put in reverse and the test was continued. Fig. 14 shows the test lane after 5 vehicle passes; ruts were about 7.8 in. deep. Fig. 15 shows the path left after 20 passes. Note the curves in the test

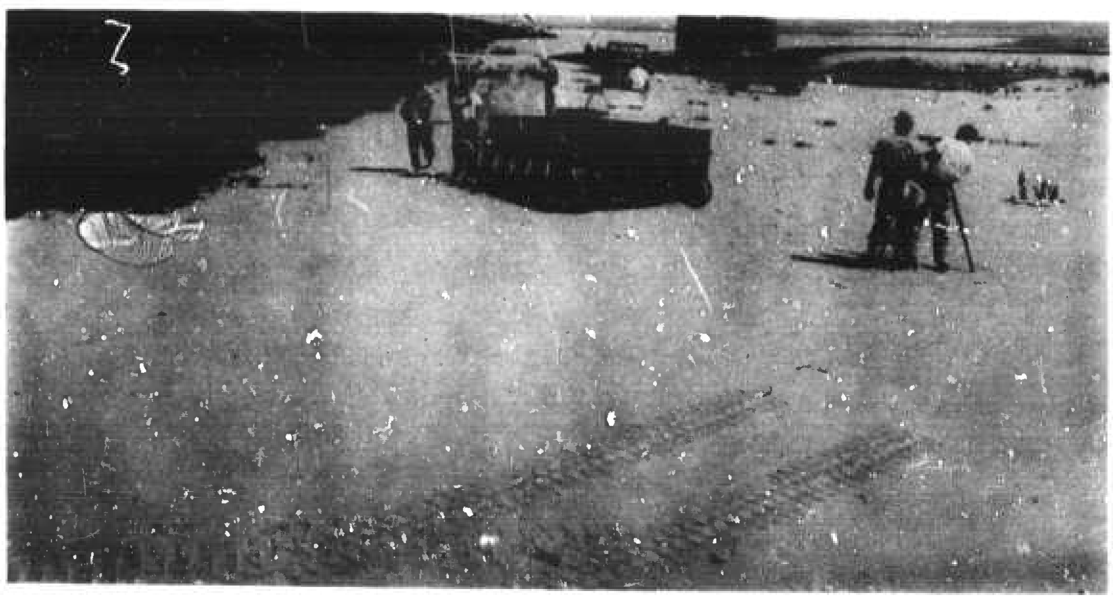


Fig. 12. Test 39, before traffic

Fig. 13. Test 39, after 1 pass

Fig. 14. Test 39, after 5 passes

Fig. 15. Test 39, after 20 passes

lane, which indicate difficulty in steering. The ruts were about 8.6 in. deep. At the end of 50 passes, the ruts were somewhat shallower, about 7.9 in. deep. In a similar test (57), on a cone index of 58 in the top 6-in. sand layer, the vehicle performed similarly except that it was not immobilized on the first pass, as had happened in test 39.

40. When loaded, the vehicle was unable to travel in reverse and could make only two or three passes going forward. The average maximum speed on the first pass was about 1 mph. Test 40 was conducted on sand with a low moisture content (1.8%), while test 56 was conducted on sand with a relatively high moisture content (20.2%), but no free water. Average cone indices were 107 and 52 in tests 40 and 56, respectively.

41. Although the vehicle (loaded or unloaded) had difficulty traveling forward and backward, it could travel laterally with ease across level sand. It could not, however, extricate itself from ruts more than about 8 in. deep by moving laterally.

42. It was concluded from these tests that the performance of the Marsh Screw in level sand was very poor because the frictional resistance of the sand against the rotors nearly matched (and in fact, often exceeded) the available tractive power of the vehicle. The unloaded vehicle performed better than the loaded vehicle. The loaded vehicle obviously performed better traveling forward than it did in reverse. Unloaded, the difference between its ability to travel forward and in reverse was not quite so obvious. The most facile movement was in the lateral direction. In the opinion of the test personnel, a more powerful engine combined with an adequate gear train would definitely improve performance in sand. It is also possible that redesign of the rotors and helixes would improve performance; however, no specific recommendation can be offered for redesign of these features.

Straight-line speed tests

43. Two tests (59 and 60) were conducted to determine the maximum speed the loaded vehicle could develop on the sand area. Test data are summarized in table 1B. As described in paragraph 26, markers were dropped from the vehicle at 10-sec intervals throughout the test course, and cone index data were measured between the interval markers. The highest speed the vehicle attained in any 10-sec interval was 2.3 mph, while the lowest

speed was 1.0 mph. The average maximum speed over the two test courses was approximately 1.6 mph. The average cone index for the 0- to 6-in. depth was about 95, while the range was from 46 to 159. No definite relations were developed between speed and cone index. It was noted, however, that higher speed could probably have been attained if greater engine power had been available.

44. In these tests, the throttle was held wide open, and steering of the vehicle was kept to the minimum necessary to follow a reasonably straight line. While the greatest speed obtained was 2.3 mph, this was maintained for only a short period during which the vehicle was not under full control. Had the driver attempted to hold a straighter course, it is very likely that the maximum speed would have been practically the same as in the repetitive-pass tests.

Maneuver-speed tests

45. Two attempts were made to conduct maneuver-speed tests over courses about 300 ft long marked with stakes at 30-ft (test 58) and 50-ft (test 61) intervals. The vehicle did not complete either test because it became immobilized in trying to maneuver between the first two stakes. Data for these tests are not shown in the tables, but cone index of the 0- to 6-in. layer averaged 76. Fig. 16 shows the Marsh Screw immobilized

Fig. 16. Marsh Screw immobilized between first two stakes in maneuver-speed test 61

between the first and second stakes in test 61. The ruts in the foreground show the approach to the beginning of the test course.

Slope-climbing tests

46. Eleven slope-climbing tests with the loaded vehicle and five with the unloaded vehicle were conducted on sand with cone indices ranging between 62 and 124+ in the 0- to 6-in. layer. One test, with the unloaded vehicle, was performed by backing up the slope. Data for these tests are contained in table 1C and are plotted in plate 6. Maintaining a straight course was just as difficult on the slopes as it had been on level sand. The maximum speed on the slopes was only about 0.5 mph. The data are limited in extent, and do not permit the development of a slope-climbing ability versus cone index curve. The data merely show that the Marsh Screw, when loaded, can climb an 18% slope but cannot climb a 21% slope on a cone index of about 75.

Towing force-slip tests

47. Several towing force-slip tests were made on level sand and the results are plotted in plate 7. Cone index and speed are given for each test. The data exhibit considerable scatter, but it is considered that the curve shown represents approximately the towing force-slip relations when the cone index is 100 to 150 in the 0- to 6-in. layer. Note that there is a pronounced decrease in vehicle speed as the curve ascends (slip increases). Also note that the two points well above the curve (65K and 65L) represent tests in which the cone index was 200. A curve for the M29C weasel, developed on a harrowed sand, is shown for comparison. This curve is taken from TM 3-240, 15th Supplement, Trafficability of Soils; Tests on Coarse-Grained Soils with Self-Propelled and Towed Vehicles, 1956 and 1957, and is not meant to represent the curve which would have been produced in tests on the natural sand beach on which the Marsh Screw was tested. However, it is believed that such a curve would have been similar to the hypothetical curve shown in plate 7, which means that in the same sand the weasel would have performed better than the Marsh Screw.

Maximum towing force tests

48. Two maximum towing force tests (64D and 65G) were conducted on level sand. The maximum towing force was measured as the load the vehicle

could pull with full throttle at a speed of approximately 0.5 mph. Additional load above that measured merely stalled the vehicle because there was insufficient power to turn the rotors. Theoretically, the maximum towing force a vehicle can develop on a given level surface, expressed as a percentage of the vehicle weight, is the same as the maximum slope it can climb on the same surface. In practice, however, it has been found that the maximum towing force attainable on level ground is usually about 2% higher than the maximum slope for the same relatively low cone index. Accordingly, the results of the slope-climbing tests (circles) and the maximum towing force tests (squares) were plotted together in plate 6 to provide sufficient data to develop vehicle performance-cone index relations. The scale for towing force is shown on the left and that for the slope on the right. A flat curve can be drawn joining the two towing tests. This curve also divides the "go" and "no-go" slope-climbing tests. The practically insignificant effect of cone index shown by this curve is not surprising since previous test programs revealed that tracked vehicles develop similar flat curves. A curve for the M29C weasel, taken from TM 3-240, 17th Supplement, Trafficability of Soils; Tests on Coarse-Grained Soils with Self-Propelled and Towed Vehicles, 1958-1961, is shown for comparison.

Discussion of slope-climbing and maximum towing force tests

49. Inasmuch as the Marsh Screw performed poorly on level sand in the repetitive-pass tests, especially while traveling in reverse, the facts that it was able to negotiate slopes up to 18%, and tow loads up to about 24% of its test weight were somewhat unexpected. Three reasons are offered: first, the vehicle was observed to travel better in a forward direction than in reverse (and the slope-climbing and towing force tests were made in a forward direction); second, the vehicle develops a much higher torque output when traveling at 0.5 mph (as it did in the slope-climbing and towing force tests) than it does at 1 to 2 mph, the speed at which the repetitive-pass and straight-line speed tests were conducted; and third, the vehicle engine may have been cooler in the slope-climbing and towing force tests (see paragraph 11).

Tests on Fine-Grained Soils

50. Tests on fine-grained soils were conducted in three locations: Albemarle Lake, Centennial Lake, and the WES reservation. Summaries of the test data and results are presented in tables 2-6 and are discussed in the following paragraphs.

Repetitive-pass tests

51. The principal purpose of the repetitive-pass tests on level terrain was to determine experimentally the vehicle cone index (VCI) of the Marsh Screw. The VCI is the minimum soil strength, expressed in terms of rating cone index (RCI), required for a vehicle to negotiate 40 to 50 passes in a straight-line path. The VCI computations for the Marsh Screw are presented in Appendix A.

52. The critical soil layer of fine-grained soils for conventional wheeled and tracked vehicles of weight similar to that of the Marsh Screw is the 3- to 9-in. depth; however, because of the possibility that the unusual means of locomotion might require redefinition of the critical layer for the Marsh Screw, soil strength data for the 0- to 6-in., 3- to 9-in., 6- to 12-in., and 9- to 15-in. depths are shown in the tables and plotted against vehicle performance in plates 8 and 9.

53. Albemarle Lake tests. Ten tests were conducted in the CH soil at Albemarle Lake with the Marsh Screw loaded (3954 lb) and one test (7) with it empty (2860 lb). The data are shown in table 2A. In addition, two tests were conducted with the M29C weasel (weight 4960 lb). Data for the weasel tests are shown in table 6. Rating cone index values are plotted against performance for the Marsh Screw and weasel in plate 8.

54. The Marsh Screw was able to complete 50 passes in tests 1, 4, 5, 7, 11, 12, and 35. These tests were conducted on test lanes covered with grass about 18 in. to 5 ft high and with 1/2 to 2 in. of water on the surface. Four of the tests (4, 5, 12, and 35) were conducted on an RCI in the 3- to 9-in. layer equal to approximately 5; the other two loaded-vehicle tests (1 and 11) were conducted on RCI's in the 3- to 9-in. layer of 34 and 16, respectively.

55. The soil in test 1 was the firmest in this series of tests. A view of the actual test site before traffic, with personnel measuring

Fig. 17. Site of test 1 at Albemarle Lake. Personnel are taking cone index measurements before traffic

Fig. 18. Test site 1 after 1 pass

before-traffic data, is shown in fig. 17. Note the high grass. Although not visible, shallow water stood in small surface depressions, such as those left by cattle hooves. Fig. 18 shows the path left by one pass of the Marsh Screw. The grass in the path has been pressed down, and rather definite traces of the Marsh Screw's helix can be seen; however, the path is poorly defined and ruts are obviously shallow. In fig. 19 the vehicle is shown on its seventh pass. Ruts remain shallow (1.5 in.).

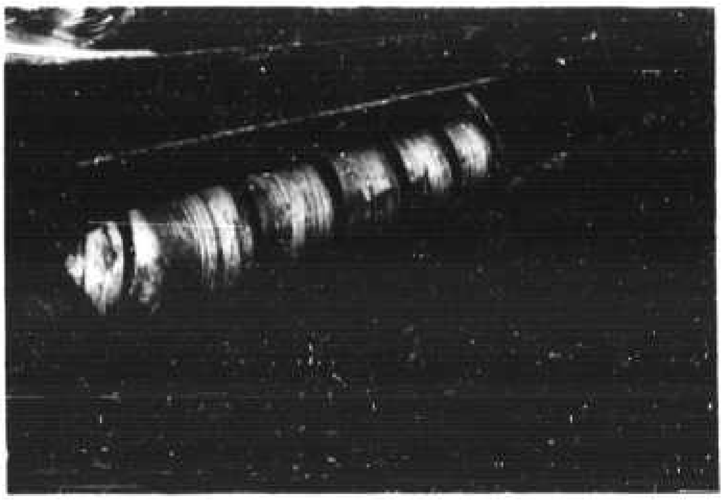


Fig. 19. Vehicle on 7th pass in test 1

Fig. 20 is a view of the test lane after 20 passes. The path is now thoroughly defined, but ruts are only slightly deeper (2.2 in.). A careful inspection of the photograph will show the presence of water in many places on the surfaces of the ruts. Fig. 21 shows the appearance of the test lane after 50 passes. There is evidence of water in the slightly deeper (2.6 in.) ruts; the grass between the ruts remains essentially undisturbed.

56. Test 35 is typical of the four "go" tests on a very soft soil condition. On the first pass, deep rutting occurred (see fig. 22). Note that the soil has flowed in both directions away from each rut, that the bottom of the Marsh Screw has flattened the grass between the ruts, and that there is considerable standing water in the ruts. Fig. 23 shows the appearance of the test lane as the Marsh Screw began its 11th pass. Fig. 24 shows the condition of the test lane after 50 passes.

Fig. 20. Test lane of test 1 after 20 passes

Fig. 21. Test lane of test 1 after 50 passes

Fig. 22. Test lane of test 35 at Albemarle Lake site after 1 pass

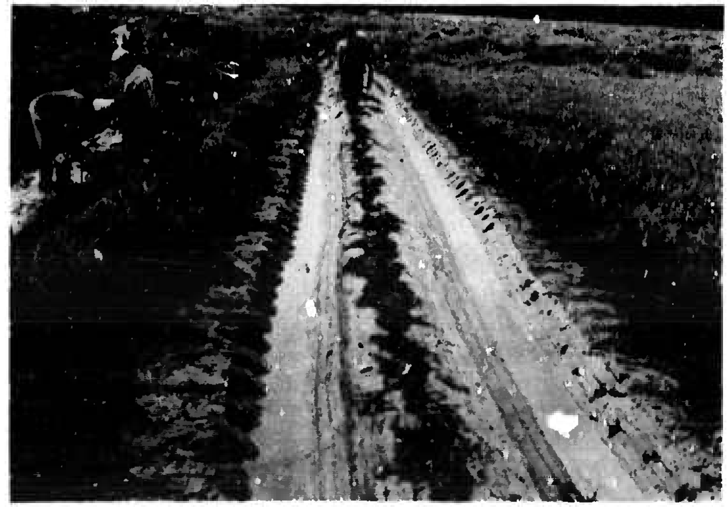


Fig. 23. Test lane of test 35 after 10 passes

Fig. 24. Test lane of test 35 after 50 passes

57. In four of the tests the Marsh Screw was unable to complete 50 back-and-forth passes in the same path (tests 2, 6, 8, and 9). Test 2 is typical of these. The soil in test 2 was only slightly less firm than in test 35. (Strengths may be compared readily in plate 8.) The condition of the test lane on the ninth pass (see fig. 25) may be compared with that of test 2 on the 11th pass (fig. 23). Fig. 25 shows deeper rutting, more pronounced dragging of the undercarriage, and a generally softer and wetter appearance of the soil. Note also the mud adhering to the rotors. By the 21st pass (fig. 26) half the diameter of the rotors was buried in soil. The vehicle was immobilized on the 36th pass (fig. 27), while traveling in reverse, when the traction being developed by the vehicle was finally not sufficient to overcome the "rolling" resistance, which had been steadily increasing in the form of bulldozing of the soil by the rear housing and soil adhering to the rotors and blades. The immobilization in this test is a rather clear-cut example of soil failure under a vehicle, and is typical of immobilizations which often occur with conventional wheeled and tracked vehicles. In this series, all immobilizations occurred while the vehicle was traveling in reverse. In these immobilizations, the rotors turned freely (100% slip). In tests 8 and 9, the vehicle was able to extricate itself with great effort, but in the other two tests, the vehicle had to be towed out.

58. Examination of plate 8 indicates that the 3- to 9-in. layer is probably the critical layer for the Marsh Screw. However, the separation between "go" and "no-go" tests is nearly as good on the basis of rating cone index in the 6- to 12-in. layer. If the 3- to 9-in. layer is accepted as the critical layer, the VCI of the vehicle is established as 5 from the data shown. This indicates that soils having RCI's greater than 5 will permit the Marsh Screw to complete 40 to 50 passes without immobilization, and soils with RCI's less than 5 will cause the Marsh Screw to become immobilized before it completes 50 passes. On the basis of experience with dozens of conventional wheeled and tracked vehicles, the quantity and quality of data shown would ordinarily have been adequate to define the vehicle's VCI; however, the Marsh Screw is not a conventional vehicle and, as will be revealed by the tests at Centennial Lake, a firm VCI cannot be established.

Fig. 25. Test lane of test 2 at Albemarle Lake site on 9th pass

Fig. 26. Test lane of test 2 on 21st pass

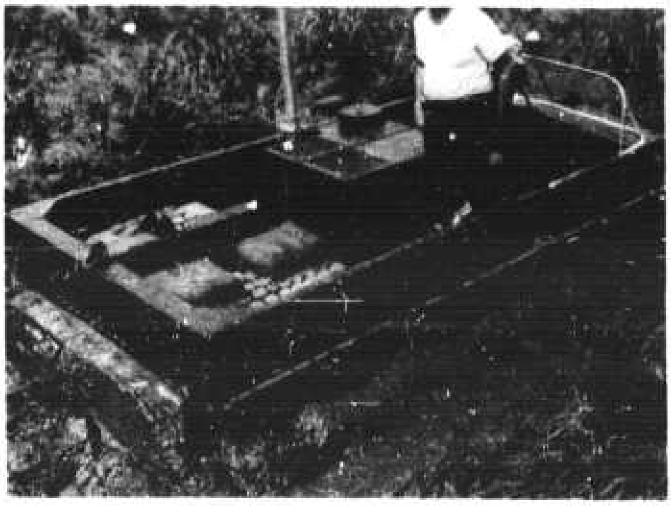


Fig. 27. Vehicle immobilized on 36th pass in test 2

59. Results of the tests at Albemarle Lake suggest that it would be almost impossible to immobilize the Marsh Screw going forward in the soft wet soil. Its good one-pass performance ability is demonstrated in tests 2 and 9 in which it completed 35 and 19 passes, respectively, on soil strength of 3 RCI in the 3- to 9-in. layer.

60. Two tests (3 and 10; see table 6) were conducted with the M29C weasel; data are plotted in plate 8 as squares. Test 3 was parallel and adjacent to test 4 of the Marsh Screw. In test 3, the weasel was immobilized on the fourth pass after completing three passes without difficulty. The Marsh Screw completed 50 passes without difficulty in test 4. In test 10, the weasel was immobilized on a straight-line path in attempting to approach the test lane. A comparison of the squares with the circles in plate 8 shows clearly that the Marsh Screw was able to complete 50 passes on weaker soil than that which caused an early immobilization of the weasel. The data indicate that the weasel requires an RCI in the 3- to 9-in. layer greater than 5. In other test programs, the weasel has occasionally completed 50 passes on a soil strength of 8 or 9 RCI; however, very sticky soils are likely to cause the weasel to become immobilized when they have built up between the tracks and the body. To allow for this, a conservative value of 25 has been assigned to the M29C weasel as its VCI for 50 passes. A one-pass VCI is estimated to be 18 for the weasel.

61. It should be noted that free water was present on the surface and in the top layer of all the soils in the Albemarle Lake tests. The presence of free water is extremely helpful in reducing the friction between the soil and the rotors of the Marsh Screw. This point will be developed further under the discussion of the Centennial Lake tests which follows.

62. Centennial Lake tests. Tests (table 3A) were conducted at Centennial Lake because the soil surface there was known to be relatively dry. Observation of the performance of the Marsh Screw at Albemarle Lake led to the suspicion that unless free water is present on or in a soil, the vehicle will probably experience difficulty. Also, it was felt that a stickier soil condition than that at Albemarle Lake would cause trouble

for the Marsh Screw. Performance-rating cone index data are plotted in plate 9.

63. Despite the fact that the RCI of the soil at Centennial Lake was greater than 5, which, according to test results at Albemarle Lake, should have meant that the Marsh Screw would not have been immobilized, each of the six tests conducted resulted in immobilization. In test 69, the vehicle was empty; it was loaded (3954 lb) for the other tests. Four of the tests (67, 68, 69, and 70) were similar in that immobilization occurred on a reverse pass early in the test and the vehicle could not turn its rotors because of insufficient power. The Marsh Screw was immobilized on its first pass in test 72 because of deep sinkage and insufficient traction in a natural soil condition. This was the only instance in the entire test program in which a first-pass immobilization occurred.

64. Test 67 is typical of four (67, 68, 69, and 70) of the five tests in which immobilizations occurred while the vehicle was traveling in reverse. Fig. 28 shows the test lane before traffic. The vehicle

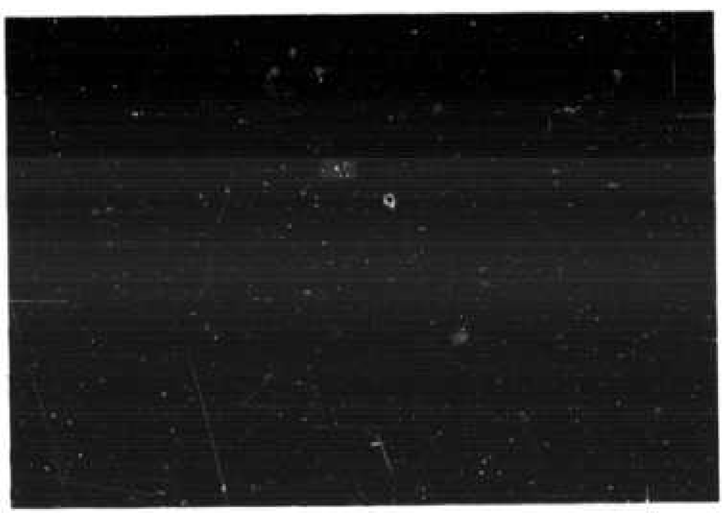


Fig. 28. Site of test 67 at Centennial Lake before traffic

proceeded down the lane, but had difficulty in maintaining a straight path. It left a rut 4.4 in. deep. The vehicle remained stationary at the end of the test lane for about 10 min while personnel measured soil data in the ruts. When an attempt was made to back it up, the vehicle merely raced its engine, and the rotors did not turn. The undercarriage of the vehicle was not dragging. The ruts were only about 4.5 in. deep. The RCI in the 3- to 9-in. layer was 9. Fig. 29 shows the right side of the vehicle, and fig. 30 the left side in the immobilized status.

Fig. 29. Right side of vehicle immobilized on 2d pass in test 67

65. Test 80 was conducted on soil which had been heavily sprinkled with water. Fig. 31 shows the test area before traffic was applied. Note the darker color of the wet soil. The Marsh Screw had visibly less

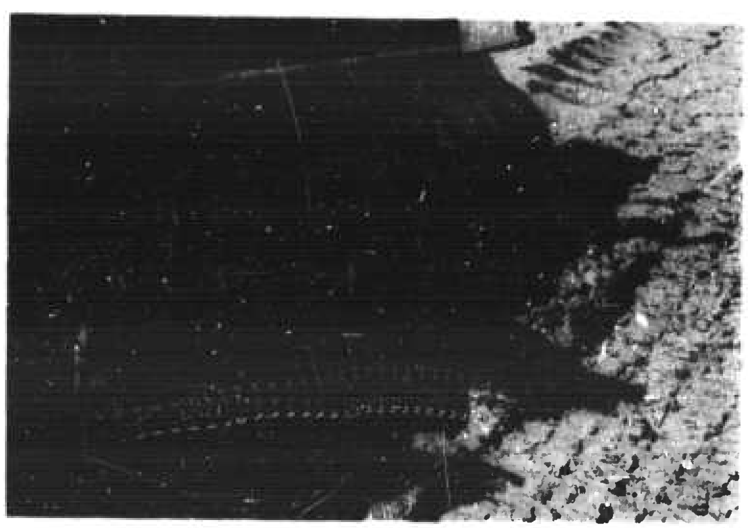


Fig. 30. Left side of vehicle immobilized on 2d pass in test 67

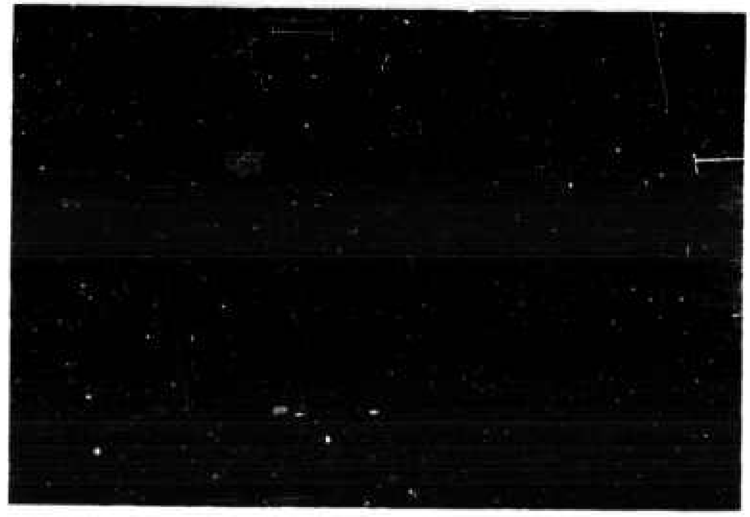


Fig. 31. Site of test 80 at Centennial Lake before traffic

difficulty in the early passes of this test than it had in tests 67-70, and was able to complete 39 passes in back-and-forth travel. It became immobilized while traveling in reverse on the 40th pass, but was able to pull forward on its own power. It made one additional pass with difficulty in a forward direction, but became immobilized on the next forward pass, the 42d one, and was unable to extricate itself. Fig. 32 shows the right rear side of the Marsh Screw in the immobilized position. Note the heavy coating of mud on the rotors.

Fig. 32. Test 80; vehicle immobilized on 42d pass

66. In test 72, the vehicle veered from the delineated test line toward softer soil and became immobilized because of high sinkage and a bulldozing action in soil that was soft (RCI = 6) and sticky. Fig. 33 shows the vehicle in the immobilized status. Note the complete coverage

Fig. 33. Vehicle immobilized on 1st pass in test 72 at Centennial Lake

of the rotor (including the helixes) by the soft, sticky soil. The friction between the soil adhering to the rotors and the natural soil was not sufficient to restrain the rotors from turning, neither was it sufficient to provide enough thrust to overcome the bulldozing action and continue forward motion. An idea of the amount of bulldozing experienced can be obtained by inspecting fig. 34; the imprint of the nose cones of the Marsh Screw rotors can be seen clearly.

Fig. 34. Test 72 immobilization area

67. When the vehicle became immobilized on a reverse pass (because of insufficient power to turn the rotors) in tests 67, 68, 69, 70, and 80, the tests were continued by driving the vehicle forward, turning out of the test lane, and then reentering it going forward. This process was repeated until the soil in the test lane had been thoroughly mixed and softened, when normal back-and-forth travel was resumed. The following tabulation lists the pass in each of these tests on which original immobilization occurred, the number of passes made in a forward direction before back-and-forth travel was resumed, and the pass number on which the "final" immobilization occurred.

Test No.	Original Immobilization Pass No.	No. of Forward Passes	Final Immobilization Pass No.
67	2	2	24 (reverse)
68	2	5	6 (forward)
69	8	6	47 (forward)
70	2	---	--
80	40	1	42 (forward)

68. One test (test 71) was conducted with the M29C weasel very close to the site of test 67 with the Marsh Screw. On a rating cone index of 8 (see table 6A) the vehicle completed 18 passes despite the fact that it began to drag on about the sixth pass. It was immobilized on the 19th pass in the conventional manner, i. e. deep sinkage, bulldozing, and spinning of tracks occurred. On the basis of this test and of previous tests with the M29C weasel, it was obvious that the performance of the M29C weasel was superior to that of the Marsh Screw in the particular soil conditions at Centennial Lake.

69. Prepared buckshot clay tests. A special test course (see table 5 for test data) was constructed of buckshot clay for the purpose of determining whether a relatively thin, soft, sticky layer over a firm one would provide difficulty for the Marsh Screw. A stockpile of buckshot clay was partially leveled and compacted. Very dry, loose, powdery buckshot clay soil was then spread about 6 in. thick on the surface, and water was applied to the surface by fire hoses intermittently over a two-day period.

70. At the time of the test (test 97), the loose soil had been wet to a depth of 3 to 4 in., but there was no free water on the surface or

Fig. 35. Test 97 on the buckshot clay area with vehicle immobilized on 1st pass (first attempt)

in the top few inches. The moisture content in the top 3 in. was 31%. The Marsh Screw managed to travel a few feet into the test lane, but became immobilized and could not proceed forward or backward (see fig. 35). Fig. 36 shows a closer view of the vehicle after an unsuccessful attempt to extricate it by twisting and turning in a generally forward direction. Note that soil is sticking to about half the rotor's surface. Fig. 37 shows the path left by the vehicle after it had moved itself laterally out of the test lane. The vehicle, traveling laterally on the firm dry soil adjacent to the test lane, proceeded to the other end of the lane and another attempt was made to negotiate the test lane. The vehicle was immobilized again after traveling forward a few feet (fig. 38). After this immobilization, the test lane and the rotors were hosed down with water. The vehicle was then able to back up (fig. 39) to the end of the lane, stop, and

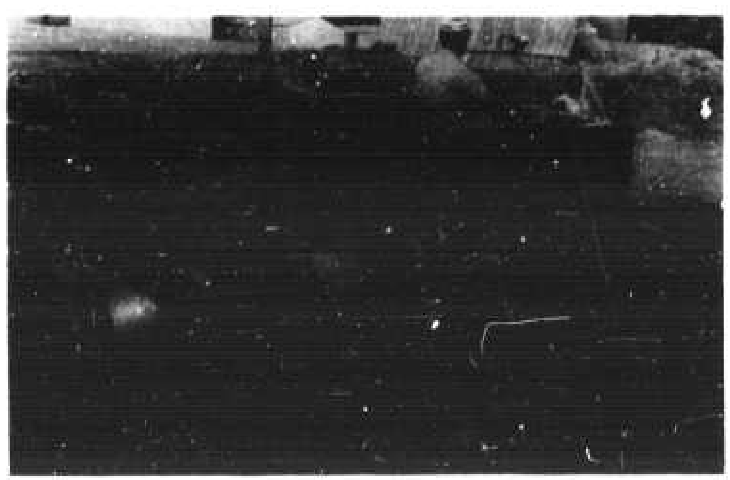


Fig. 36. Marsh Screw after attempting to extricate itself in test 97

Fig. 37. Path left by Marsh Screw in test 97 after extricating itself laterally

Fig. 38. Test 97; vehicle again immobilized on 1st pass (second attempt)

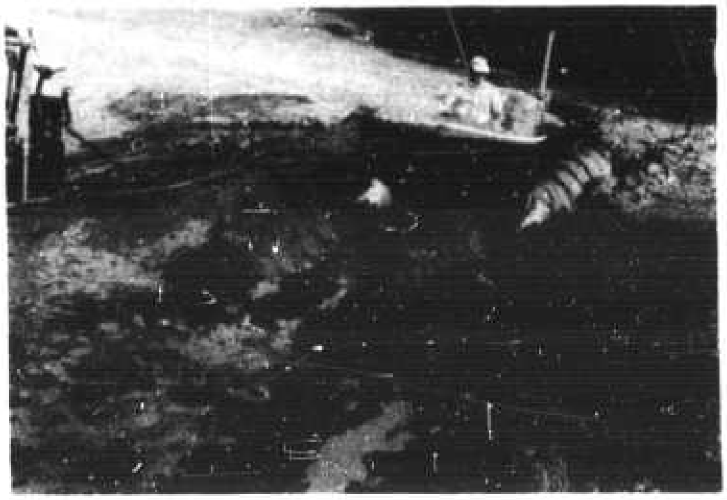


Fig. 39. After test 97 lane was wetted, vehicle could back up on 2d pass

proceed forward. As long as the vehicle was operating in the freshly wetted area (moisture content of soil was approximately 48%), the friction was low. Note that the rotor shown in fig. 39 is covered with a thin layer of wet soil. The vehicle was able to make several back-and-forth passes as long as the friction remained low. However, when the vehicle proceeded into the drier soil at the end of the test lane and the thin layer of wet soil on the rotors was wiped off, the friction increased suddenly and the vehicle was immobilized, i.e. it was no longer able to move its rotors.

71. Discussion of repetitive-pass tests in fine-grained soils. As stated earlier, establishment of an experimental VCI for the Marsh Screw is not a clear-cut procedure. The vehicle easily ran 50 passes at Albemarle Lake on CH soil which was definitely softer than the CH soil at Centennial Lake and in the prepared buckshot clay test lane. Yet on the latter two soils, immobilization occurred. While the three CH soils differed somewhat in grain size and Atterberg limits, these differences do not account for the differences in performance of the Marsh Screw. Rather, one must look to the friction between the soil and the rotors to explain the difference. At Albemarle Lake, where free water was present (and friction was low), the vehicle had no great difficulty in traveling except where the soil was so soft that the vehicle sank until its undercarriage dragged and it bulldozed soil in trying to move forward. In each such case the vehicle was able to spin its rotors. Even on the very firm conditions at Albemarle Lake, the presence of water and moist, soft grasses created low friction and permitted the vehicle to travel. (Very firm conditions were tested in the towing tests to be discussed later.)

72. At Centennial Lake, the dry, crusty surface soil was quickly mixed with the wetter soil below. The result was a sticky mass that resisted movement of the vehicle's rotors because of friction. Consequently, the Marsh Screw was immobilized on an early reverse pass with only small sinkage because the rotors could not turn against the restraining frictional force of the soil. Two exceptions to this pattern occurred: (a) the vehicle was immobilized on a wetter, softer condition on the first pass going forward when it sank so deeply that its turning rotors could not develop the thrust required to bulldoze the soil ahead, and (b) the vehicle was able to make 39 passes before becoming immobilized (rotors

not turning) when the surface of the soil was artificially wetted.

73. The testing on the prepared buckshot soil test lane also clearly demonstrated the extreme importance of low friction to the successful operation of the Marsh Screw. Unable to move on the soil when no free water was present, the Marsh Screw moved easily when water was sprinkled on the surface, and continued to move freely until mixing of the wet soil with drier soil (and perhaps evaporation) had reduced the water content of the soil upon which it was operating.

74. The majority of immobilizations occurred while the vehicle was traveling in reverse. The loaded vehicle is designed to ride with a high bow in water. The rear end will thus begin to drag and bulldoze before the front end in a repetitive-pass test on soil. In the immobilizations that occurred at Albemarle Lake, the vehicle had sunk deeply and was bulldozing, with rotors turning. However, at Centennial Lake, the vehicle's "initial" immobilizations occurred, for the most part, with no bulldozing, and were the result of insufficient power to turn the rotors against the soil. According to the manufacturer, the screw action is exactly the same whether the vehicle travels forward or backward, but the torque and final drive output are slightly higher in low forward gear (ratio of 2.45:1) than in reverse (ratio of 2.20:1). The unequal weight distribution partially explains the generally better performance while traveling forward. It was noted, however, that in the tests at Centennial Lake which were continued after the initial immobilization, subsequent immobilizations occurred while the vehicle was traveling forward in back-and-forth tests. The advantage of traveling forward, therefore, probably cannot be considered great.

Straight-line speed tests

75. Three straight-line speed tests were conducted at Albemarle Lake using the procedures described in paragraph 26. Detailed data are shown in table 2C. Pertinent data, averaged for 100-ft lengths of each test course, are shown in the following tabulation and plotted in plate 10.

Station	Average Rating Cone Index in 3- to 9-in. Layer			Average Speed, mph		
	Test 98	Test 99	Test 100	Test 98	Test 99	Test 100
0+00 to 1+00	10	10	52	5.6	5.2	2.3
1+00 to 2+00	26	24	51	2.1	1.8	1.9
2+00 to 3+00	17	21	54	2.0	1.8	2.1
3+00 to end	38	30	58	2.1	1.9	1.4

76. Test 100 was run on firmer soil than were the other two tests. The soil conditions in test 98, which were about the same as those of test 99, are illustrated in figs. 40-43. A maximum speed of approximately 5 mph was attained on the lowest rating cone index (about 10). The speed decreased rapidly to about 2 mph on an RCI of approximately 20, and remained fairly constant thereafter.

Maneuver-speed tests

77. Test 101. In this test, the driver was instructed to follow a path that zigzagged between stakes placed 50 ft apart in a straight line 417 ft long, with the minimum possible deviation from the straight line. The following tabulation shows pertinent data measured and plate 10 includes a plot of speed (projected to the straight-line course) versus rating cone index in the 3- to 9-in. layer. A maximum average speed of approximately 4 mph was attained on an RCI of about 5. Speed decreased at a moderate rate to about 2 mph on an RCI of approximately 17, and decreased at a slow rate thereafter. The vehicle required 140 sec to complete the 417-ft course, and actually traveled a distance of 442 ft. The average

Station	Average Rating Cone Index in 3- to 9-in. Layer	Average Speed, mph
0+00 to 1+00	5	3.64
1+00 to 2+00	14	2.75
2+00 to 3+00	20	1.61
3+00 to 4+00	41	1.58
4+00 to 4+17	58	1.30

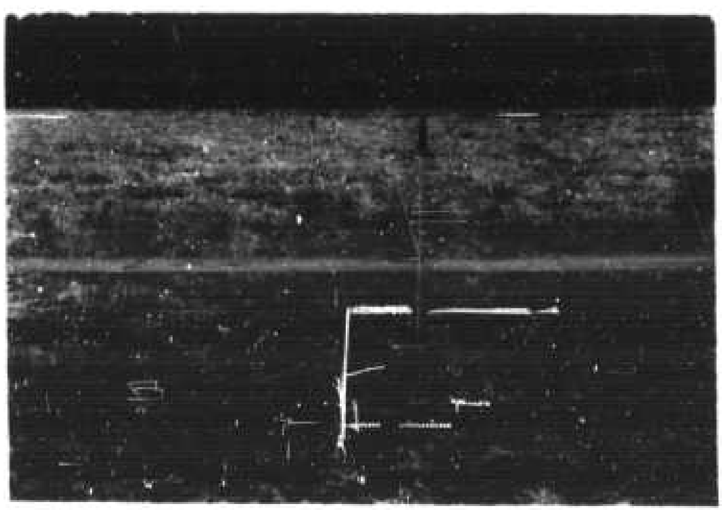


Fig. 40. Test 98; straight-line speed test course at Albemarle Lake; sta 3+50 in foreground

Fig. 41. Test 98; beginning of straight-line speed test course

Fig. 42. Test 98; middle of straight-line speed test course

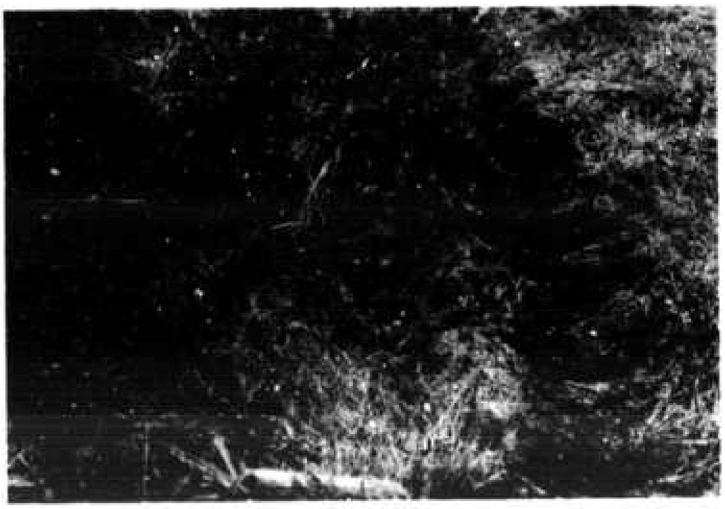
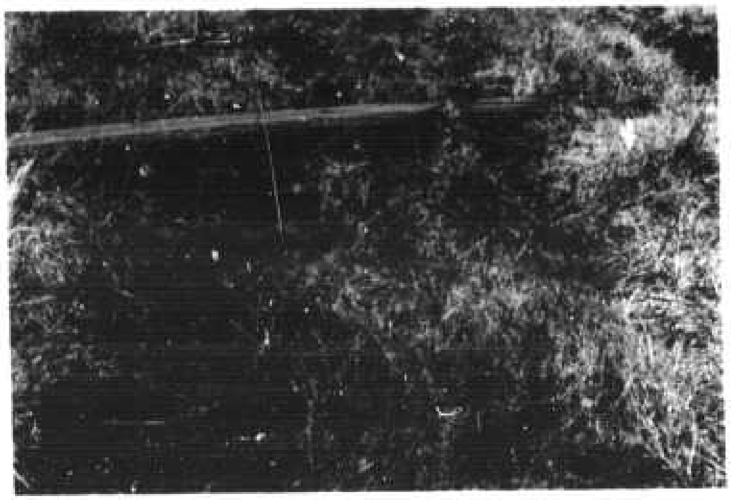


Fig. 43. Test 98; end of straight-line speed test course



speed developed along the straight course was 2 mph; the actual average speed of the moving vehicle on its sinuous course was 2.2 mph.

78. Test 102. In this test, the driver was instructed to complete the course in the fastest possible time, using lateral movement of the vehicle to maneuver between stakes spaced at 50-ft intervals along a 525-ft-long path whenever he felt this would be advantageous. The time required to complete the course was 150 sec, and the actual distance traveled was 630 ft. The net speed was thus 2.4 mph, and the actual speed was 2.9 mph. No attempt was made to relate speed to soil strength in this test because of the complexity caused by the lateral movements. The RCI varied fairly uniformly from about 3 at the start of the course to about 40 at the end.

79. Test 103. A straight-line course 480 ft long was marked with stakes 30 ft apart. The driver was instructed to maneuver between the stakes in the fastest possible time. He employed a significant amount of lateral movement in traversing the course. The total time was 210 sec; the total actual distance covered was 616 ft. The average net speed for the course was 1.6 mph; the actual average speed of movement over the 616 ft was 2.8 mph. The soil condition was very similar to that in test 102.

Obstacle tests

80. Two tests were conducted on the ML soil in the simulated rice field (described in paragraph 17) with the Marsh Screw, and for comparative purposes, one test was conducted with the M29C weasel. Soil data and results of these tests are summarized in table 4B. Times required for the vehicles to cross the dikes, accelerometer values recorded on each dike, and cone index of 3- to 9-in. layer between dikes are shown in plate 11. The data show that the weasel traveled through the test course and over each dike in less time than the Marsh Screw. The weasel traversed the entire test course in 28 sec; the Marsh Screw required an average of 78 sec. The data also show that the Marsh Screw developed greater accelerations than the weasel in all three directions, and on every dike. The dikes which were compacted to a cone index of well above 300 were partially cut into by the pontoons of the Marsh Screw, while the weasel maneuvered over the dikes without cutting them. Fig. 44 shows dike 4 before traffic, and fig. 45 shows all four dikes after the Marsh Screw had traveled over them.

81. Fig. 46 shows that while performance of the Marsh Screw over

Fig. 44. Dike 4 of simulated rice field before traffic

Fig. 45. All four rice-field dikes after traffic of Marsh Screw; dike 4 in foreground

Fig. 46. Marsh Screw climbing soft, wet earth mound at Albemarle Lake

the firm, stabilized dikes of the simulated rice field was generally considered poor, the vehicle could climb 3-ft-high, wide-based, soft mounds of wet earth (at Albemarle Lake) with little difficulty.

82. Attempts were made to test an M37 3/4-ton truck and an M38A1 jeep on the prepared test course, but both of these vehicles were immobilized on dike 2.

Towing force-slip tests

83. Data collected in towing force-slip tests with the Marsh Screw at Albemarle Lake and Centennial Lake are shown in tables 2B and 3E, respectively, and similar data for the M29C weasel are shown in table 6B. All data are plotted in plate 12. The Marsh Screw test data appear as circles (Albemarle) and squares (Centennial), while the weasel test data appear as triangles. Test numbers, rating cone index, and vehicle speed are shown for each test.

84. When a sufficient number of tests have been made with a vehicle in the same or similar soil conditions, it usually is feasible to develop a towing force-slip curve. Such a curve is shown for the M29C weasel, and it is fairly typical for tracked vehicles on fine-grained soils. The dashed extension of the curve is assumed on the basis of previous knowledge of towing force-slip relations for the M29C weasel in fine-grained soils.

85. The many data points shown for the Marsh Screw cover a wide range of soil strength and appear, at first glance, to be meaningless. However, it was possible to select eight points which represented a narrow range of strength, i.e. RCI between 19 and 31. These points, six of which represent a wet surface at Albemarle Lake, appeared to define a fairly smooth curve, which was therefore drawn and is shown in plate 12. Note that the curve reaches a maximum value of towing force (42%) at a slip of about 28%, and that thereafter towing force decreased with increasing slip. In general, the other data points in plate 12 for the Marsh Screw appear to be located properly with respect to the curve drawn. Note, for example, that tests 74B and 76 conducted on soil with RCI's much lower than 19 fall well below the curve, while tests conducted on soil with higher RCI's are, for the most part, above or to the left of the curve. While there are some anomalies among the data points, it nevertheless is considered that the curve shown for the Marsh Screw can be

accepted, at least tentatively, as a reasonably accurate measure of its towing force-slip relations on fine-grained soil with an RCI between about 20 and 30.

86. The curve for the M29C weasel lies well above that for the Marsh Screw. Moreover, the M29C curve indicates retention of maximum towing force with increasing slip, whereas the Marsh Screw curve indicates a reduction in towing force (from a peak value) with increasing slip. Since the small difference in soil strength involved is not considered to be the cause of the relative positions of the two curves, it must be concluded that the M29C exhibits superior towing force-slip characteristics.

Maximum towing force tests with vehicle traveling forward

87. Only the tests in which the vehicle was traveling at a speed of 0.5 to 0.6 mph at maximum throttle were used in this analysis. (Maximum towing force tests at Albemarle and Centennial Lakes are illustrated in figs. 47 and 48, respectively.) In most cases, faster travel resulted in

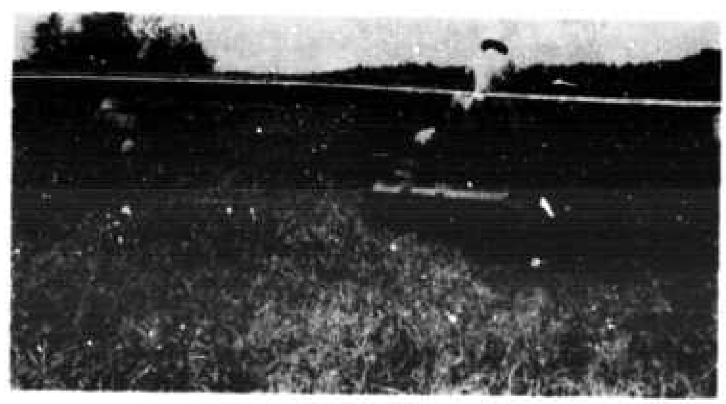


Fig. 47. Test 28, maximum towing force test on grass-covered soil at Albemarle Lake

Fig. 48. Test 76, maximum towing force test on bare soil at Centennial Lake

smaller towing forces, and slower travel in larger towing forces, on the same soil conditions. The speed selected for this analysis, while very slow, appeared to be commensurate with the normal speed of about 2 mph attainable at no load on most soil conditions tested in this program.

88. The towing force and rating cone index data from Albemarle and Centennial Lakes and WES are shown in tables 2B, 3B, and 4A, respectively, and are plotted in plate 13. For each test, the test number, slip (when measured), and speed are shown. Because of the difference in vehicle performance in repetitive-pass tests at the two lake sites, data in this analysis have been identified with the site at which the test was run. The Albemarle Lake tests appear as circles, Centennial Lake tests as squares, and the one WES test as a triangle.

89. The smooth curve drawn for the Albemarle points appears to fit them quite well and also appears to include the one WES point. A maximum drawbar pull at about 40 RCI appears reasonable, since at this strength the soil is firm enough to limit rutting but soft enough to allow penetration of the helixes. Although the soil at the WES site did not meet the criterion of surface wetness met by the Albemarle tests, there was a good stand of grass at the WES site that provided the low friction the Marsh Screw seems to need for good performance.

90. The curve drawn for the Centennial Lake soils was influenced by the shape of the Albemarle-WES curve. It does not represent its points quite as well as did the Albemarle-WES curve. Note that two Centennial Lake tests (82C and 84B) fall among the Albemarle test data. Test 82C is the only one conducted at Centennial Lake on grass-covered soil; the soil in the remainder of the tests at Centennial Lake was bare. The soil in all the Albemarle-WES tests was covered with grass. No such explanation exists for the poor fit of test 84B to the curve.

91. In view of the generally poor performance in the repetitive-pass tests at Centennial Lake, the high maximum towing forces developed on the same soil are surprising. Note, for example, from plate 13, that the Marsh Screw developed a pull equal to 42% of its weight on an RCI of about 40, whereas in the repetitive-pass tests it was immobilized on the second pass on an RCI in the 3- to 9-in. layer of 11 (see test 70, plate 9). The towing forces generated are explained qualitatively by three observations:

first, the vehicle may have been at its maximum efficiency for these tests (see paragraph 11); second, the vehicle performs better traveling forward; and third, at the slow speed of travel in the towing tests (about 0.5 mph) the torque output was significantly greater than it was at the speed of travel in the repetitive-pass tests (about 1.5 mph). (See Appendix B.)

92. A similar curve for the weasel (taken from TM 3-240, Supplement 14) is shown for comparison. Note that at RCI's less than about 35 the performance of the Marsh Screw exceeds that of the weasel both at Albemarle Lake and Centennial Lake, whereas the M29C weasel shows a decided advantage on RCI's greater than 40.

Maximum towing force tests
<u>with vehicle traveling laterally</u>

93. On firm soil, the Marsh Screw could travel laterally better than it could move forward or backward. Six maximum towing force tests, three each at Albemarle Lake and Centennial Lake, were conducted with the vehicle, weighing 3954 lb, traveling laterally. Fig. 49 shows the Marsh Screw towing laterally. Results of these tests are shown in tables 2B and 3B and in plate 14. The shape of the performance curve for these tests more closely resembles the maximum towing force curve for conventional vehicles than the curves shown in plate 13 when the Marsh Screw was traveling forward. It also closely resembles the curve for the M29C weasel, which is included in plate 14. (This curve is the same one shown in plate 13.) This close resemblance is probably caused by the fact that the vehicle had adequate power when traveling laterally on firm soil. At an RCI of 300, the vehicle could develop a maximum pull of 65% of its weight; however, lateral

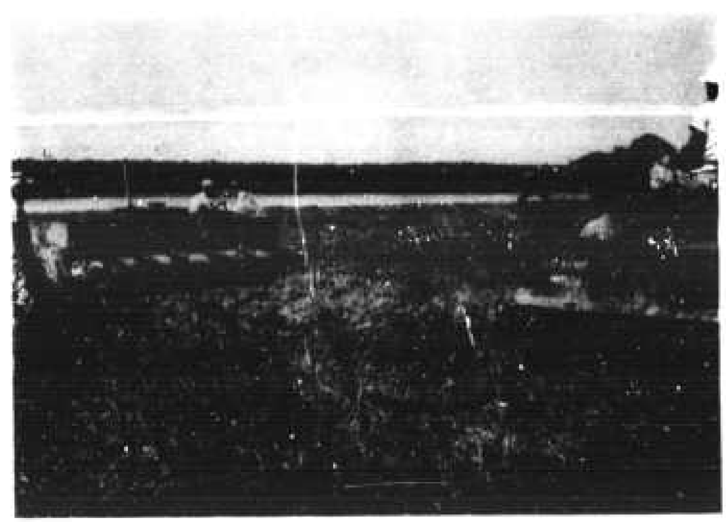


Fig. 49. Marsh Screw towing laterally

pulls were noticeably harmful to the structural components of the vehicle.

Towed-vehicle tests

94. An attempt was made to tow the Marsh Screw at Albemarle Lake on an RCI of 300+ using the M29C weasel. However, the pintle hook on the Marsh Screw was pulled out of shape in moving the vehicle, and the attempt was halted.

95. On the same soil condition, a force of 650 lb was required to move the Marsh Screw laterally at a speed of about 1 mph.

Tests in Water

96. Quantitative tests in water were not scheduled, but several excursions of the Marsh Screw into the Mississippi River for motion picture purposes permitted some general observations. The vehicle appeared to be quite stable in water, responded readily to steering, and traveled at what was estimated to be 5 or 6 mph. It had no difficulty, beyond the normal difficulty it had on level sand, in entering the water from the sand beach (slope about 1 to 6%) and returning to the beach from the water.

Tests in Transitional Zone Between Deep Water and Water-Free Soil Surfaces

97. Quantitative tests to determine the Marsh Screw's performance, in terms of speed, across the zone between deep water and water-free soil surfaces were not scheduled since previous testing in marshland conditions indicated the vehicle performed well, at least on a one-pass basis, in areas where ample water was present to wash the rotors free of cohesive soils. On a number of occasions, the Marsh Screw traveled across this zone at Albemarle Lake to reach deep water in order to wash the rotors free of soil after completion of tests in which soil adhered to the undercarriage and rotors. On a typical "run" from deep water to water-free soil surfaces, the Marsh Screw appeared to travel at speeds of 5 and 6 mph in deep water; when the vehicle approached the water's edge and the rotor blades began to bite into the soil beneath the water, the vehicle's speed was noted to increase considerably (perhaps to 20 or 25 mph) through a certain zone where water covered the soil surface, but vehicle speed decreased

rather suddenly as the vehicle ran out onto the water-free soil surfaces. In attempts to reach deep water from water-free soil surfaces, the weasel became immobilized in the very soft soil (RCI approximately 5). Water was approximately 2 in. deep where the vehicle became immobilized.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

98. Based on the results of the testing accomplished in this program with the Marsh Screw and the M29C weasel, and upon known performance of the latter in previous test programs,* the following conclusions are offered regarding the performance of the Marsh Screw on various media, particularly in comparison to the M29C weasel.

Performance on sand

99. The performance of the Marsh Screw Amphibian on a natural beach sand with a cone index ranging from 50 to 150 was as follows:

Vehicle Condition	Performance
Unloaded	Could complete 50 or more back-and-forth passes, but steering was difficult, progress labored, and speed slow, especially in the early stages of the tests.
Loaded	Could not travel in reverse and could only make two or three passes going forward.
	Attained a maximum speed on the first pass of 2.3 mph, but only for a brief period. The average maximum speed attained was about 1.6 mph.
	Could not execute even moderately severe maneuvers.
	Could climb an 18% slope, but could not climb a 21% slope.
	On a CI of approximately 100 to 150, developed enough thrust to barely propel itself at about 1 mph and about 20% slip.
	On a CI of about 100 to 150, could exert a maximum towing force of 26% at 55% slip and at a speed of only 0.5 mph when traveling at full throttle. For slips greater than 55%, towing force remained constant at about 26%.
Loaded or unloaded	Could travel laterally with greater speed and facility than it could travel forward or backward, but could not be steered.

* WES TM 3-240, Trafficability of Soils, and Supplements 1-17 thereto; and WES MP 4-439, Trafficability Tests with the Airoll on Organic and Mineral Soils (August 1961).

100. In general, the performance of the Marsh Screw on sand must be classified as poor. On the same sand, the M29C weasel has been found to travel several degrees of magnitude faster, with less effort, less steering difficulty, and far greater maneuverability. The M29C weasel also could have climbed slopes and pulled loads approximately twice as great.

Performance on fine-grained soils

101. On CH soils upon which free water was standing or which contained free water near the surface, i.e. at Albemarle Lake, the loaded Marsh Screw:

a. Could always make one pass going forward regardless of the cone index.

b. Could complete 50 passes or more as long as the RCI in the critical layer was 5 or greater.

c. Traveled faster (about 6 mph) on soft soil (RCI's in the order of 10) than on firmer soils (RCI's of 20 to 60).

d. Was able to maneuver between stakes 30 to 50 ft apart without a serious reduction in net speed.

e. Traveling forward at 0.5 mph, developed a maximum towing force of 42% of its weight on an RCI of about 40. At lower strengths, maximum towing force decreased rapidly; at higher strengths, there was a less rapid decrease in towing force.

f. Traveling forward, developed a towing force-slip curve in which towing force increased with increasing slip to a maximum value of 42% towing force at 28% slip; thereafter towing force decreased with increasing slip.

g. Traveling laterally, developed a maximum towing force of 66% on firm soil. The curve of towing force versus soil strength developed closely resembled that for the M29C weasel.

h. Could not be towed on a firm soil without permanent damage to the pintle hook.

102. The Marsh Screw showed an advantage over the M29C weasel in extremely soft soils, up to an RCI of approximately 40; at higher RCI's, the M29C weasel performed better than the Marsh Screw.

103. On CH soils in which no free water was present, i.e. at Centennial Lake and on the prepared buckshot clay test lane, the loaded Marsh Screw:

a. Could make one pass forward provided the RCI was greater than 8 but not greater than about 300.

b. Became immobilized on the first pass on an RCI below 8. Deep sinkage, bulldozing, and spinning of tracks attended the immobilization.

c. On soil strengths of about 300 CI, became immobilized on the first pass because the vehicle's power was not sufficient to turn the rotors against the frictional forces acting between the soil and the rotors.

d. Could not make more than a few passes on an RCI of 8 to 15. In such sticky soil, the vehicle usually was immobilized on a backward pass. Sinkage was not excessive; rotors could not be turned.

e. Traveling forward at 0.5 mph, developed a maximum towing force of about 35% of its weight on an RCI of about 30. At lower and higher strengths, the towing force diminished rapidly.

f. Was able to travel when soil which otherwise would not allow its rotors to turn was sprinkled with water.

g. Could travel easily in a lateral direction on firm soils that would not permit it to travel forward or backward.

104. The loaded Marsh Screw was decidedly inferior to the M29C weasel in every important aspect of performance on the sticky, water-free, soft soils at Centennial Lake except one; namely, the Marsh Screw developed higher towing force (in percentage of vehicle weight) than the M29C weasel on RCI's less than about 35. In the sticky, firm soil on the prepared buckshot clay test lane, the Marsh Screw could not even turn its rotors until the soil was sprinkled with water.

Performance over obstacles

105. In simulated rice-field obstacle-crossing tests, the Marsh Screw traversed the test course in 78 sec (average), and the M29C weasel traversed the course in 28 sec. The obstacle-crossing speed of the Marsh Screw is limited by the austere, unsprung design of the rotor suspension system. The shocks (as indicated in terms of accelerations) experienced by the Marsh Screw were consistently higher than those experienced by the M29C weasel, often as much as 2-1/2 to 3 times as high. The Marsh Screw took almost three times as long to traverse the course as did the M29C weasel.

General performance

106. The Marsh Screw's engine became overheated quickly when it was being strained, i.e. when the vehicle was traveling or attempting to travel

on soils that provided high frictional resistance. Overheating apparently resulted in reduced vehicle power for traction purposes.

107. Steering of the vehicle was relatively difficult in all but the softest soils and where free water was present.

108. Obstacle-crossing ability of the Marsh Screw over firm, stabilized dikes was poor because of its rigidity.

109. The vehicle could travel with ease in a lateral direction on firm soils on which it could not even turn its rotors in a forward or reverse direction; however, when traveling laterally, the vehicle could not be steered.

110. The vehicle performed better when traveling forward than when traveling in reverse.

111. Most immobilizations occurred when vehicle power was not sufficient to overcome the friction of the soil against the rotors. Greater engine power and a properly designed transmission would undoubtedly increase the ability of the Marsh Screw to travel under such conditions. The improved performance on such soils would probably not be at the expense of its excellent performance on very wet, soft soils (unless weight and contact pressure were increased disproportionately).

Recommendations

112. The testing program, while not exhaustive, is considered to have been sufficiently comprehensive to evaluate the performance of the vehicle in mineral soils. Therefore, no additional testing of the present model in mineral soils is recommended.

113. The unusual propulsion system of the Marsh Screw makes it appear suitable for use in muskeg, snow, and very soft marshes of the type found in southwest Louisiana. It is recommended that its performance in such media be tested.

114. It is recommended that efforts be made to improve the performance of the vehicle in highly sticky or frictional soil conditions. Specifically, it is suggested that Teflon coating be applied to the rotors, that the engine power and gear train be redesigned to provide greatly increased traction, and that consideration be given to auxiliary traction

systems mainly for traveling on firm soils, including ground effects systems and means of steering the vehicle while it is traveling laterally.

Table 1

Tests on Coarse-Grained Soil (SP, River Beach), Marsh Screw Amphibian

A. Repetitive-Pass Tests on Level Soil

Test No.	Vehicle Weight lb	Immobilization Yes/No	Immobilization Pass No.	CI Data Pass No.	Cone Index at Depths, in. 0	3	6	9	12	15	18	21	24	30	36	Avg Cone Index of Layers 0-6 in.	3-9 in.	6-12 in.	Moisture Content, %, of Layers 0-6 in.	6-12 in.	Dry Density, lb/cu ft, of Layers 0-6 in.	6-12 in.	Avg Rut Depth in.
39	2860	No	---	0	3	36	140	232+	287+	300+	--	--	--	--	--	60	136+	220+	2.7	3.6	92.4	85.7	--
				1	27	168	272	300+	--	--	--	--	--	--	--	156+	247+	291+	2.1	3.5	92.9	88.0	5.6
				5	16	138	266+	300+	--	--	--	--	--	--	--	140+	235+	300+	--	--	---	--	7.8
				20	14	150	264+	300+	--	--	--	--	--	--	--	143+	238+	300+	--	--	---	--	8.6
				50	8	126	251+	300+	--	--	--	--	--	--	--	128+	226+	300+	--	--	---	--	7.9
57	2860	No	---	0	14	61	99	130	162	166+	192+	200+	236+	300+	--	58	97	130	--	--	---	--	--
				2	10	48	92	139+	182+	212+	226+	263+	260+	300+	--	50	93+	138+	--	--	---	--	6.8
				10	8	48	84	143	176	212+	260+	300+	--	--	--	47	92	134	--	--	---	--	9.5
				20	8	54	99	159+	190+	223+	268+	300+	--	--	--	54	104+	149+	--	--	---	--	10.1
40	3954	Yes	3	0	6	94	221	300+	--	--	--	--	--	--	--	107	205+	274+	1.8	5.2	91.4	86.1	--
				1	28	174	283	300+	--	--	--	--	--	--	--	162	252+	294+	--	--	---	--	5.5
				3*	17	138	277	300+	--	--	--	--	--	--	--	144	238+	292+	--	--	---	--	7.6
56	3954	Yes	3	0	22	76	58	75	105	198	262+	300+	--	--	--	52	70	79	20.2	23.4	104.2	--	--
				2*	2	11	42	112	190	182	180	250	300+	--	--	18	55	115	20.6	25.8	103.7	--	4.8

(Continued)

* All passes were made in forward gear.

Table 1 (Continued)

B. Straight-Line Speed Tests (SP, River Beach)

Test No.	Vehicle Weight lb	Location Between 10-sec Markers	Speed Data: 10-sec Distance ft	Speed Data: Speed fps	Speed Data: Speed mph	Cone Index at Depths, in.: 0	3	6	9	12	15	18	21	24	30	36	Avg Cone Index of Layers: 0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.
						300-ft Test Lane															
59	3954	1 and 2	19	1.9	1.3	18	65	78	115	132	150	200	215	178	232+	300+	54	86	108	132	161
		2 and 3	30	3.0	2.0	28	30	135	120	110	180	220	180	158	198	270+	81	112	122	137	170
		3 and 4	31	3.1	2.1	15	80	190	270	267+	242+	300+	--	--	--	--	95	180	242+	260+	270+
		4 and 5	31	3.1	2.1	40	80	95	250	300+	--	--	--	--	--	--	72	142	215+	283+	300+
		5 and 6	34	3.4	2.3	28	75	132	205	255	202+	210+	280+	300+	--	--	78	137	197	221+	222+
		6 and 7	30	3.0	2.0	32	130	220	250+	250+	250+	300+	--	--	--	--	127	200+	240+	250+	267+
		7 and 8	28	2.8	1.9	40	120	273	300+	--	--	--	--	--	--	--	146	233+	293+	300+	--
		8 and 9	28	2.8	1.9	68	152	253	300+	--	--	--	--	--	--	--	159	237+	286+	300+	--
		9 and 10	24	2.4	1.6	20	100	180	300+	--	--	--	--	--	--	--	100	193+	260+	300+	--
		10 and 11	31	3.1	2.1	*															
		11 and 12	15	1.5	1.0	*															
		Total	301		1.8 Avg																
						200-ft Test Lane															
60	3954	1 and 2	15	1.5	1.0	32	158	230	200	222	135	172	170	178	192	180	140	196	217	186	176
		2 and 3	19	1.9	1.3	26	132	172	220+	250+	230+	238+	228+	235+	250+	250+	111	175	214+	233+	239+
		3 and 4	29	2.9	2.0	25	118	200	232+	240+	265+	270+	238+	242+	240+	240+	114	183+	224+	246+	258+
		4 and 5	34	3.4	2.3	25	72	108	110	122	132	150	165	185	255+	300+	68	97	113	121	135
		5 and 6	32	3.2	2.2	25	128	135	102	105	145	162	220	285+	300+	--	96	122	114	117	137
		6 and 7	21	2.1	1.4	20	105	70	100	100	120	120	155	165	250	210	65	92	90	107	113
		7 and 8	19	1.9	1.3	15	50	72	110	122	130	142	150	180	155	162	46	77	101	121	131
		8 and 9	19	1.9	1.3	12	70	150	115	130	195	155	130	110	240	205	77	112	132	147	160
		9 and 10	14	1.4	1.0	14	95	140	160	135	200	180	160	155	250	285	83	132	145	165	172
		Total	202		1.5 Avg																

(Continued)

* No data taken within this area.

Table 1 (Continued)

C. Slope-Climbing Tests (SP, River Beach)

Test No.	Vehicle Weight lb	Immobilization Yes/No	Immobilization Pass No.	Slope %	Cone Index at Depths, in. 0	3	6	9	12	15	18	21	24	30	36	Avg Cone Index of Layers 0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	Moisture Content, %, of Layers 0-6 in.	6-12 in.	Density, lb/cu ft, of Layers 0-6 in.	6-12 in.
42	2860	No	---	6	10	78	211+	282+	296+	300+	--	--	--	--	--	100+	190+	263+	293+	299+	0.19	1.70	99.6	93.0
43	2860	No	---	5	7	58	208	292+	300+	--	--	--	--	--	--	91	186	257+	297+	300+	0.24	2.30	100.7	91.7
44	2860	No	---	4	6	64	223+	296+	300+	--	--	--	--	--	--	98+	194+	273+	299+	300+	--	--	---	--
45	2860	No	---	6	6	64	241	300+	--	--	--	--	--	--	--	104	202+	280+	300+	--	--	--	---	--
46*	2860	No	---	11	5	72	217	279+	286+	292+	294+	300+	--	--	--	98	189	261+	286+	291+	0.54	3.10	97.6	91.7
47	3894	No	---	10	28	113	186+	234+	256+	285+	297+	298+	286+	296+	300+	109+	178+	225+	258+	279+	2.70	2.50	97.3	94.2
48	3894	No	---	6	19	105	222	267+	298+	300+	--	--	--	--	--	115	198+	262+	288+	299+	1.10	4.20	101.7	95.6
49	3894	No	---	7	7	71	184	273+	299+	300+	--	--	--	--	--	87	176+	252+	291+	300+	2.40	2.10	99.1	92.0
50	3894	No	---	4	15	135	212	283+	300+	--	--	--	--	--	--	121	210+	264	294+	300+	4.20	2.40	92.0	91.8
51	3894	No	---	8	16	116	215	290+	300+	--	--	--	--	--	--	116	207+	268+	297+	300+	2.90	3.70	88.0	89.7
52	3894	No	---	12	12	80	188	234+	265+	283+	--	--	--	--	--	93	167+	229+	261+	283+	4.0	3.5	93.1	90.2
53	3894	No	---	13	14	113	245+	294+	300+	--	--	--	--	--	--	124+	217+	280+	298+	300+	1.8	3.6	96.5	91.3
54A	3894	No	---	16	8	84	184	258+	292+	300+	--	--	--	--	--	92	175+	245+	283+	297+	1.5	2.6	99.0	91.4
54B	3894	Yes	1	22	8	79	180+	250+	282+	298+	300+	--	--	--	--	89	170+	237+	277+	293+	--	--	---	--
55A	3894	No	---	18	4	50	165	233+	240+	285+	300+	--	--	--	--	73	149+	213+	253+	275+	0.48	3.0	99.8	92.0
55B	3894	Yes	1	21	6	52	128	221+	281+	295+	300+	--	--	--	--	62	134+	210+	266+	292+	--	--	---	--

(Continued)

* Running in reverse.

Table 1 (Concluded)

D. Towing Force-Slip Tests on Level Soil (SP, River Beach)

Test No.	Vehicle Weight, lb	Towing Force lb	Towing Force % Test Weight	Slip %	Speed mph	0- to 6-in. Cone Index
64A	3954	10	0.25	19	1.4	94
64B	3954	710	17.9	32	1.0	94
64C	3954	825	20.8	41	0.7	94
64D*	3954	915	23.1	35	0.5	94
64E	3954	985	24.8	61	0.2	94
64F	3954	1035	26.1	58	0.3	115+
65A	3954	20	0.5	31	1.5	149+
65B	3954	490	12.3	33	1.2	149+
65C	3954	600	15.1	32	0.8	149+
65D	3954	720	18.1	39	0.7	149+
65E	3954	800	20.2	44	0.6	149+
65F	3954	725	18.3	40	0.7	171+
65G*	3954	945	23.9	32	0.5	171+
65H	3954	1065	26.8	64	0.3	171+
65K	3954	1065	26.8	38	0.3	200+
65L	3954	1120	28.2	32	0.4	200+

* Used in maximum towing force analysis.

Table 2

Tests on Fine-Grained Soil (CH, Albemarle Lake), Marsh Screw Amphibian

A. Repetitive-Pass Tests on Level Soil

Test No.	Vehicle Weight lb	Immobilization Yes/No	Immobilization Pass No.	Data Pass No.	Cone Index at Depths, in.											Avg Cone Index of Layers					Avg Remolding Index of Layers					Rating Cone Index of Layers					Moisture Content % of Dry Weight of	
					0	3	6	9	12	15	18	21	24	30	36	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	6-12 in.
1	3954	No	--	0	25	36	43	50	46	44	47	52	61	70	78	35	43	46	47	46	0.66	0.79	0.66	0.64	0.62	23	34	30	30	28	65.1	63.7
				1	22	34	40	50	40	40	40	48	56	65	73	32	41	43	43	40												
				5	24	37	44	48	42	43	47	52	59	70	73	35	43	45	44	44												
				10	24	36	42	42	36	36	35	45	48	56	66	34	40	40	38	36												
				20	26	38	48	54	38	39	46	54	62	74	80	37	47	47	44	41												
				50	23	36	45	42	41	44	52	60	70	76	82	35	41	43	42	46												
2	3954	Yes	36	0	4	4	6	9	12	17	18	22	24	32	42	5	6	9	13	16	0.52	0.58	0.64	0.60	0.55	3	3	6	8	9	157.0	111.4
4	3954	No	--	0	5	6	7	9	11	14	17	20	22	26	29	6	7	9	11	14	0.74	0.74	0.75	0.76	0.73	4	5	7	8	10	145.7	124.2
5	3954	No	--	0	5	5	6	10	16	22	27	30	30	38	41	5	7	11	16	22	0.55	0.66	0.76	0.73	0.70	3	5	8	12	15	145.3	106.6
				30	6	10	17	25	27	31	35	45	40	43	46	11	17	23	28	31												
				50	5	9	14	24	27	35	39	--	--	--	--	9	16	22	29	34												
6	3954	Yes	26	0	2	3	5	10	16	20	24	30	34	40	46	3	6	10	15	20	0.67	0.70	0.72	0.76	0.80	2	4	7	11	16	153.1	101.5
7	2860	No	--	0	3	4	5	10	15	22	25	25	28	37	35	4	6	10	16	21	0.72	0.65	0.58	0.70	0.83	3	4	6	11	17	161.2	102.9
				1	2	4	6	12	18	21	21	23	26	32	34	4	7	12	17	20												
				10	2	4	7	12	16	22	22	24	28	35	36	4	8	12	17	20												
				50	2	3	7	15	26	29	27	24	30	36	40	4	8	16	23	27												
[illegible]	3954	Yes	2	0	2	3	4	4	6	6	8	10	12	16	26	3	4	5	5	7	0.73	0.70	0.68	0.72	0.77	2	3	3	4	5	161.5	149.7
[illegible]	3954	Yes	20	0	1	2	4	7	12	19	23	25	25	35	34	2	4	8	13	18	0.46	0.71	0.70*	0.75*	0.80*	1	3	6	10	14	161.5	95.2
11	3954	No	--	0	4	6	18	38	40	36	36	44	56	52	68	9	21	32	38	37	0.74	0.76	0.78	0.72	0.67	7	16	25	27	25	109.6	72.5
				1	4	21	33	44	37	40	56	62	58	73	71	19	33	38	40	44												
				10	11	34	33	29	34	53	60	57	61	64	72	26	32	32	39	49												
				50	8	27	29	29	36	56	60	58	65	71	72	21	28	31	40	51												
12	3954	No	--	0	2	2	4	12	16	22	28	41	42	42	42	3	6	11	17	22	0.55	0.64	0.72	0.70	0.68	2	4	8	12	15	153.8	109.6
				1	3	8	15	22	26	29	37	34	39	32	38	9	15	21	26	31												
				10	2	8	15	24	35	34	37	38	40	40	46	8	16	25	31	35												
35	3954	No	--	0	2	3	4	11	14	23	31	25	24	32	31	3	6	10	16	23	0.79	0.79	0.79	0.66	0.53	2	5	8	10	12	[illegible]	[illegible]
				1	2	6	10	16	22	20	18	26	30	35	38	6	11	16	19	20												
				50	1	3	6	12	20	26	28	26	30	36	38	3	7	13	19	25												

(Continued)

Note: Rotors turned in all immobilizations.
* Estimated remolding index from adjacent tests.

Table 2

Tests on Fine-Grained Soil (CH, Albemarle Lake), Marsh Screw Amphibian

A. Repetitive-Pass Tests on Level Soil

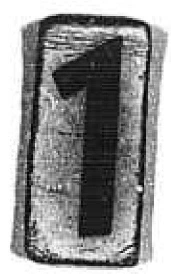
Avg Remolding Index of Layers					Rating Cone Index of Layers					Moisture Content, % of Dry Weight of Layers			Dry Density lb/cu ft, of Layers			Avg Rut Depth	Remarks
0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	6-12 in.	12-18 in.	0-6 in.	6-12 in.	12-18 in.	in.	
0.66	0.79	0.66	0.64	0.62	23	34	30	30	28	65.1	63.7	57.2	60.8	61.5	67.1	--- 0.9 1.4 1.8 2.2 2.6	Test area covered with grass about 18 to 20 in. high. After five passes vehicle operated with ease, very little rutting. Surface water in the ruts. Vehicle completed 50 passes with ease. Rotors were clean at the end of the test
0.52	0.58	0.64	0.60	0.55	3	3	6	8	9	157.0	111.4	99.3	29.4	43.8	45.6	---	Soil in test lane too soft to support a man. Area covered with thick grass about 4 to 5 ft high. After six passes vehicle began to drag; after 28 passes the grass between ruts not visible. After 34 passes operator began to lose control of vehicle steering. Immobilized on 36th pass in reverse. Could move back and forth about 15 ft. Mud filled the area between the helixes of the rotors
0.74	0.74	0.75	0.76	0.73	4	5	7	8	10	145.7	124.2	96.7	33.6	36.8	46.4	---	Test run parallel to test 3 (vessel). Vehicle dragged and bulldozed some soil during test but completed 50 passes with ease and came out of test lane under own power with no difficulty. Free water in ruts during test
0.55	0.66	0.76	0.73	0.70	3	5	8	12	15	145.3	106.6	120.3	33.4	42.4	38.0	--- --- ---	Test run parallel to test 4, vegetation and soil conditions same. Belly of vehicle began to drag after 20 passes and steering difficulty developed after 24 passes. Water began to enter vehicle ruts after 26 passes. Considerable mud buildup was in evidence on rotors and helixes after 45 passes (reverse). Vehicle completed 50 passes with ease, having no apparent trouble, and was able to remove itself from the test lane
.67	0.70	0.72	0.76	0.80	2	4	7	11	16	153.1	101.5	110.1	32.1	45.2	40.4	---	Lane covered with grass about 4 to 5 ft high; soil was very soft, bluish in color. Vehicle had difficulty completing 1st pass--had to back up and pull forward about four times. Then completed 25 passes with very little difficulty but was immobilized completely on 26th pass (reverse); could move backward and forward 1 or 2 ft but could not remove itself from lane. Belly of vehicle dragging after 1st pass; rear was bulldozing large amount of soil. Rotors and helixes completely covered with the soft soil
.72	0.65	0.58	0.70	0.83	3	4	6	11	17	161.2	102.9	75.2	30.2	44.4	53.4	--- 5.9 6.9 ---	Area, area conditions, and soil conditions are same as those of tests 2 and 6. Soil was soft and sticky. No free water in evidence in the test lane throughout conduct of test. Vehicle rotors disturbed test lane considerably. Vehicle rode on top of thick mixture of soil and vegetation on each pass. Completed 50 passes with ease. After 50th pass vehicle was loaded and four passes run in same ruts. With added load vehicle cut design into soil mass and traveled with extreme difficulty
.73	0.70	0.68	0.72	0.77	2	3	3	4	5	161.5	149.7	96.4	28.4	32.4	45.6	---	Vehicle immobilized on 2d pass (reverse). Vegetation and soil piled up in rear of vehicle apparently causing immobilization. Vehicle could pull forward and then in reverse to point of immobilization. Pulled out of test lane without help
.46	0.71	0.70*	0.75*	0.80*	1	3	6	10	14	161.5	95.2	75.6	29.7	46.3	55.2	---	No vegetation in test lane, soil bluish in color. Vehicle had no trouble on 1st pass but began to bulldoze soil in lane on 2d pass; soil began to build up on rotors. Undercarriage began dragging on 9th pass. Soil build-up and high slip percentage occurring on 17th pass; motor beginning to labor. After 19 passes rotors slipping badly; vehicle hardly moving through lane. Immobilization occurred on 20th pass (reverse); pulled forward about 5 ft; unable to get out of test lane. Pulled itself out of test lane by continued maneuvering and with considerable difficulty
.74	0.76	0.78	0.72	0.67	7	16	25	27	25	109.6	72.5	56.2	41.6	56.3	68.0	--- 4.4 7.0 9.2	On 2d and 4th passes soil thrown by rotors 3 to 4 ft from vehicle. Vehicle rotors formed fairly even, clean ruts by 7th pass and soil trying to build up on rotors between helixes. Completed 50 passes with ease. Vehicle undercarriage about 3 in. above center of lane
.55	0.64	0.72	0.70	0.68	2	4	8	12	15	153.8	109.6	71.0	31.2	43.2	60.7	--- --- ---	About 1 in. surface water covering entire test lane. Vegetation about 3 to 4 ft high; very thick grass. After ten passes soil mass flowing back into ruts; vehicle traveling with ease. Some bulldozing of soil with rear of vehicle in evidence. Some difficulty in making the 40th through the 50th passes but completed 50 passes
.79	0 79	0.79	0.66	0.53	2	5	8	10	12	159.4	84.7	74.4	30.4	50.9	56.4	--- --- ---	1 to 2 in. of water on surface; test lane covered with grass 4 to 5 ft high; soil very soft, bluish color. After 1st pass 2 in. of water in ruts. Vehicle had no trouble completing 40 passes. Some rotor slip observed after 40 passes; completed 50 passes with little difficulty

(Continued)

Table 2 (Continued)

B. Towing Force Tests on Level Soil (CH, Albemarle Lake)

Test No.	Vehicle Weight, lb	Towing Force lb	Towing Force % Test Weight	Speed mph	Slip %	Cone Index at Depths, in. 0	3	6	9	12	15	18	21	24	30	36	Avg Cone Index of Layers 0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	Avg Remoldi[ng] 0-6 in.	3-9 in.
14*	3954	1200	30.3	1.1	--	17	13	20	33	47	54	58	65	67	67	74	17	22	33	45	53	0.75	0.80
15*		1500	38.0	1.3	--	23	25	39	53	51	51	57	65	71	75	81	29	39	48	52	53	0.71	0.78
16*		1700	43.0	0.5	--	24	29	53	55	45	47	51	58	61	67	78	35	46	51	49	48	0.71	0.78
17		1650	42.0	0.6	25.4	19	40	52	40	35	39	43	49	57	72	86	37	44	42	38	39	0.69	0.71
18		1550	39.0	0.7	36.9	14	36	48	43	39	44	50	57	65	79	91	33	42	43	42	44	0.61	0.68
19		1500	38.0	0.7	56.2	16	37	45	38	38	40	47	51	58	67	82	33	40	40	39	42	0.77	0.77
20		900	23.0	0.3	83.7	4	10	49	50	41	38	41	47	50	56	59	21	36	47	43	40	0.59	0.53
21		650	16.0	0.7	70.5	7	18	43	43	43	38	45	53	63	68	71	23	35	43	41	42	0.55	0.65
22		500	13.0	0.5	74.8	5	21	46	46	49	47	49	56	62	69	71	24	38	47	47	40	0.78	0.76
23*		1700	43.0	0.5	--	21	24	43	43	48	52	56	62	68	64	81	29	37	45	48	52	0.80	0.85
24*		1700	43.0	0.7	--	20	27	57	39	33	37	43	47	49	59	71	35	41	43	36	38	0.61	0.68
25*		1200	30.0	0.8	--	5	10	38	61	49	52	56	61	68	73	74	18	36	49	54	52	0.65	0.69
26*		1100	28.0	0.7	--	4	5	21	48	55	57	54	58	61	61	62	10	25	41	53	55	0.89	0.75
27*		1300	33.0	0.5	--	4	4	7	49	65	56	54	56	58	59	59	5	20	40	57	58	0.85	0.75
28*		1050	26.6	0.5	--	111	300+	300+	300+	226+	172+	112+	101+	94+	94+	98+	237+	300+	275+	233+	170+	**	**
29†		2600	65.5	---	--	111	300+	300+	300+	226+	172+	112+	101+	94+	94+	98+	237+	300+	275+	233+	170+	**	**
30A†		1800	45.4	---	--	32	48	49	44	52	62	66	73	82	91	92	43	47	48	53	60	0.78	0.72
30B†		1400	35.3	---	--	12	21	36	43	44	50	60	65	74	80	84	23	33	41	46	51	0.69	0.70
36A*		1500	37.8	1.3	--	39	40	45	60	67	93	126	113	113	101	90	41	48	57	73	95	0.72	0.66
36B*		1800	45.4	1.1	--	60	61	60	52	68	96	82	87	79	79	82	60	57	60	72	82	0.72	0.66
37A*		1400	35.3	0.0	--	19	29	35	50	67	107	134	81	84	69	67	28	38	51	75	103	0.72	0.66
37B*		1800	45.4	0.0	--	21	35	49	70	80	113	138	107	103	92	95	35	51	66	88	110	0.72	0.66
37C*		1200	30.2	0.8	--	47	47	65	55	81	113	116	114	132	120	114	53	56	67	83	103	0.70	0.56
37D		1875	47.4	1.1	29.0	41	48	49	57	72	108	116	112	133	133	114	46	51	59	79	99	0.84	0.82
38A*		800	20.2	0.0	--	3	3	7	10	16	21	20	20	22	27	29	4	7	11	16	19	0.80	0.80
38B*		700	17.6	0.0	--	3	3	7	11	20	22	24	27	30	39	31	4	7	13	18	22	0.79	0.79
90*		1400	35.3	0.5	--	110	121	108	79	60	66	54	46	52	55	66	113	103	82	68	60	0.84	0.82
91*		950	23.9	0.6	--	134	158	148	98	97	74	72	70	66	72	68	147	135	114	90	81	--	1.02
92*		1075	27.1	0.5	--	147	138	118	102	74	76	56	62	68	77	80	134	119	98	84	69	0.88	0.80
93*		1250	31.6	0.5	--	131	156	96	106	98	106	120	126	118	122	124	128	119	100	103	108	--	0.97
94*		1710	43.1	0.9	--	86	98	103	78	56	65	60	64	73	78	80	96	93	79	66	60	--	0.89



(Continued)

* Maximum towing force tests, slip not measured.
** Soil too firm to perform remolding test.
† Vehicle traveling laterally.

Table 2 (Continued)

B. Towing Force Tests on Level Soil (CH, Albemarle Lake)

			Avg Cone Index of Layers					Avg Remolding Index of Layers					Rating Cone Index of Layers					Moisture Content, % of Dry Weight of Layers				Dry Density lb/cu ft, of Layers		
24	30	36	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-1 in.	0-6 in.	6-12 in.	12-18 in.	0-6 in.	6-12 in.	12-18 in.
67	67	74	17	22	33	45	53	0.75	0.80	0.85	0.69	0.53	13	18	28	31	28	95.6	113.8	62.4	77.6	40.2	64.9	54.2
71	75	81	29	39	49	52	53	0.71	0.78	0.84	0.73	0.61	21	30	40	38	32	70.2	88.2	57.4	71.9	49.2	63.6	57.2
61	67	78	35	46	51	49	48	0.71	0.78	0.84	0.73	0.61	25	36	43	36	29	83.6	73.7	60.1	59.8	54.9	64.0	64.8
57	72	86	37	44	42	38	39	0.69	0.71	0.73	0.72	0.70	26	31	31	27	27	77.8	74.8	66.2	51.2	54.4	59.2	69.6
65	79	91	33	42	43	42	44	0.61	0.68	0.75	0.65	0.54	20	29	32	27	24	85.3	92.5	61.8	50.0	46.3	--	70.0
58	67	82	33	40	40	39	42	0.77	0.77	0.77	0.63	0.49	25	31	31	25	21	90.1	67.4	70.5	50.7	61.4	58.0	70.6
50	56	59	21	36	47	43	40	0.59	0.53	0.48	.63	0.79	12	19	23	27	32	123.6	82.8	73.6	61.5	50.0	57.4	63.1
63	68	71	23	35	43	41	42	0.55	0.65	0.76	0.69	0.76	13	23	33	28	32	111.1	87.3	74.2	50.8	48.4	57.0	71.6
62	69	71	24	38	47	47	48	0.78	0.76	0.74	0.66	0.58	19	29	35	31	28	99.1	77.7	69.7	52.3	53.2	58.1	68.7
68	64	81	29	37	45	48	52	0.80	0.85	0.90	0.72	0.55	23	31	40	35	29	69.2	74.9	54.6	82.7	53.3	66.8	51.9
49	59	71	35	41	43	36	38	0.61	0.68	0.75	0.61	0.46	21	28	32	22	17	91.3	68.3	54.8	71.4	56.3	67.7	57.3
68	73	74	18	36	49	54	52	0.65	0.69	0.72	0.67	0.63	12	25	35	36	33	105.6	77.0	61.5	77.7	53.9	63.2	55.0
61	61	62	10	25	41	53	55	0.89	0.75	0.60	0.59	0.59	9	19	25	31	32	127.7	127.9	68.8	79.8	36.2	59.3	54.0
58	59	59	5	20	40	57	58	0.85	0.75	0.65	0.58	0.51	4	15	26	33	30	143.6	152.6	59.0	70.3	32.2	64.9	57.8
94+	94+	98+	237+	300+	275+	233+	170+	**	**	**	**	**	237+	300+	275+	233+	170+	14.5	37.6	20.3	33.6	78.6	91.6	81.4
94+	94+	98+	237+	300+	275+	233+	170+	**	**	**	**	**	237+	300+	275+	233+	170+	14.5	37.6	20.3	33.6	78.6	91.6	81.4
82	91	92	43	47	48	53	60	0.78	0.72	0.65	0.70	0.75	34	34	31	37	45	89.7	61.4	73.7	50.1	[illegible]	56.3	71.2
74	80	84	23	33	41	46	51	0.69	0.70	0.71	0.68	0.65	16	23	29	31	33	112.5	80.8	71.6	60.0	52.1	57.8	64.5
113	101	90	41	[illegible]	57	73	95	0.72	0.66	0.60	0.44	0.27	30	32	34	32	26	---	---	--	--	--	--	--
79	79	82	60	57	60	72	82	0.72	0.66	0.60	0.44	0.27	43	36	36	32	22	---	---	--	--	--	--	--
84	69	67	28	38	51	75	103	0.72	0.66	0.60	0.44	0.27	20	25	31	33	28	81.7	78.5	67.7	66.7	53.8	59.8	59.4
103	92	95	35	51	66	88	110	0.72	0.66	0.60	0.44	0.27	25	34	40	39	30	81.7	78.5	67.7	66.7	53.8	59.8	59.4
132	120	114	53	56	67	83	103	0.70	0.56	0.42	0.31	0.20	37	31	28	26	21	55.7	66.2	70.7	37.0	60.0	58.1	83.6
133	133	114	46	51	59	79	99	0.84	0.82	0.80	0.60	0.41	39	42	47	47	41	66.3	56.0	63.3	36.6	66.8	62.1	82.3
22	27	29	4	7	11	16	19	0.80	0.90	0.81	0.67	0.53	3	6	9	11	10	---	---	--	--	--	--	--
30	39	31	4	7	13	18	22	0.79	0.79	0.79	0.66	0.53	3	5	10	12	12	---	---	--	--	--	--	--
52	55	66	113	103	82	68	60	0.84	0.82	0.80	--	--	95	84	66	--	--	53.9	52.9	55.1	--	63.5	67.6	--
66	72	[illegible]	147	135	114	90	81	--	1.02	0.84	0.66	--	--	138	86	59	--	29.9	36.4	44.2	49.5	72.0	74.4	69.0
68	77	80	134	119	98	84	69	0.88	0.80	0.72	--	--	118	95	70	--	--	51.5	48.4	62.6	--	72.4	61.9	--
118	122	124	128	119	100	103	108	--	0.97	0.71	0.46	--	--	115	71	47	--	35.1	48.4	42.5	--	68.3	59.6	--
73	78	80	96	93	79	66	60	--	0.89	[illegible]	0.82	--	--	83	68	54	--	53.3	61.6	54.9	--	57.5	--	--

(Continued)

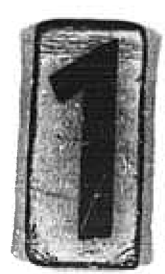
Table 2 (Continued)

C. Straight-Line Speed Tests (CH, Albemarle Lake)

Test No.	Vehicle Weight, lb	Location Between 10-sec Markers	Speed Data: 10-sec Distance ft	Speed fps	Speed mph	Cone Index at Depths, in.: 0	3	6	9	12	15	18	21	24	30	36	Avg Cone Index: 0-6 in.	3-9 in.	6-12 in.
98	3954	1 and 2	89	8.9	6.1	4	6	8	22	38	48	61	69	72	54	58	6	12	23
		2 and 3	31	3.1	2.1	10	12	16	34	60	70	70	78	100	120	110	13	21	37
		3 and 4	30	3.0	2.0	17	17	32	50	62	62	84	93	110	108	96	22	33	48
		4 and 5	29	2.9	2.0	11	24	44	66	74	78	95	100	105	110	107	26	45	61
		5 and 6	35	3.5	2.4	12	13	23	58	73	70	71	83	97	93	106	16	31	51
		6 and 7	29	2.9	2.0	12	12	16	38	52	62	68	81	62	65	78	13	22	35
		7 and 8	26	2.6	1.8	12	11	20	30	55	28	25	55	60	35	75	14	20	35
		8 and 9	30	3.0	2.0	16	16	31	40	43	40	41	54	68	65	97	21	29	38
		9 and 10	35	3.5	2.4	20	20	40	48	50	48	44	74	91	88	112	27	36	46
		10 and 11	32	3.2	2.2	40	40	40	55	50	50	60	55	70	70	80	40	45	48
		11 and 12	27	2.7		45	40	40	60	75	90	120	110	110	110	120	42	47	58
99	3954	1 and 2	85	8.5	5.8	4	6	8	22	38	48	61	69	72	54	58	6	12	23
		2 and 3	30	3.0	2.0	10	10	12	50	48	55	40	52	88	52	58	11	24	37
		3 and 4	28	2.8	1.9	10	12	16	60	54	50	50	60	68	65	62	13	29	43
		4 and 5	24	2.4	1.6	6	24	40	44	54	70	90	94	72	100	100	23	36	46
		5 and 6	26	2.6	1.8	6	10	52	60	64	70	70	80	82	94	80	23	41	59
		6 and 7	27	2.7	1.8	10	8	40	40	32	38	60	102	62	72	80	19	29	37
		7 and 8	26	2.6	1.8	10	9	29	40	47	50	65	91	86	78	91	16	26	39
		8 and 9	23	2.3	1.6	10	10	18	40	62	62	70	80	110	84	102	13	23	40
		9 and 10	26	2.6	1.8	16	17	34	47	48	51	65	75	76	95	111	22	33	43
		10 and 11	30	3.0	2.0	20	17	32	47	51	53	69	81	87	100	122	23	32	43
		11 and 12	31	3.1	2.1	19	19	35	37	46	33	46	56	58	70	81	24	30	39
		12 and 13	25	2.5	1.7	30	40	32	54	64	64	72	90	102	112	120	34	42	50
100	3954	1 and 2	36	3.6	2.56	65	65	62	70	68	65	72	75	70	70	65	64	66	67
		2 and 3	33	3.3	2.25	48	65	62	65	42	55	52	48	48	62	68	58	64	56
		3 and 4	30	3.0	2.05	60	62	75	60	52	60	62	58	58	82	98	66	66	62
		4 and 5	24	2.4	1.64	82	78	75	60	65	60	68	68	68	68	88	78	71	67
		5 and 6	28	2.8	1.91	85	90	62	52	52	45	55	52	52	45	62	79	68	55
		6 and 7	29	2.9	1.98	58	72	60	55	55	60	75	90	90	85	110	63	62	57
		7 and 8	32	3.2	2.18	55	52	45	60	72	85	95	115	125	135	162	51	52	59
		8 and 9	37	3.7	2.52	90	75	52	62	68	72	82	92	100	118	138	72	63	61
		9 and 10	30	3.0	2.05	105	90	70	70	60	55	65	70	80	90	105	88	77	67
		10 and 11	18	1.8	1.23	75	95	75	50	50	55	60	65	80	65	85	82	73	58
		11 and 12	20	2.0	1.37	75	95	75	50	50	55	60	65	80	65	85	82	73	58

Summary by 100-ft Stations

Station	Average Rating Cone Index 3- to 9-in. Layer: Test 98	Test 99	Test 100	Average Speed, mph: Test 98	Test 99	Test
0+00 to 1+00	10	10	52	5.6	5.2	2.3
1+00 to 2+00	26	24	51	2.1	1.8	1.9
2+00 to 3+00	17	21	54	2.0	1.8	2.1
3+00 to End	39	30	58	2.1	1.9	1.4



(Continued)

* Values assumed to be same as preceding measured value.
** Estimated from adjacent test lane.

Table 2 (Continued)

C. Straight-Line Speed Testa (CH, Albemarle Lake)

Cone Index at Depths, in.								Avg Cone Index of Layers					Remolding Index of Layers					Rating Cone Index of Layers				
9	12	15	18	21	24	30	36	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.
22	38	48	61	69	72	54	58	6	12	23	36	49	0.79	0.78	0.75	0.68	0.60	5	9	17	24	29
34	60	70	70	78	100	120	110	13	21	37	55	67	•	•	•	•	•	10	16	28	37	40
50	62	62	84	93	110	108	96	22	33	48	58	69	•	•	•	•	•	17	26	36	39	41
66	74	78	95	100	105	110	107	26	45	61	73	82	•	•	•	•	•	20	35	46	50	49
58	73	70	71	83	97	93	106	16	31	51	67	71	0.76	0.70	0.65	0.58	0.52	12	22	33	39	37
38	52	62	68	81	62	65	78	13	22	35	51	61	•	•	•	•	•	10	15	23	30	32
30	55	28	25	55	60	35	75	14	20	35	38	36	•	•	•	•	•	11	14	23	22	19
40	43	40	41	54	68	65	97	21	29	38	41	41	•	•	•	•	•	16	20	25	34	21
48	50	48	44	74	91	88	112	27	36	46	49	47	0.99	0.88	0.77	0.72	0.67	27	32	35	35	31
55	50	50	60	55	70	70	80	40	45	48	52	53	•	•	•	•	•	40	40	37	37	36
60	75	90	120	110	110	110	120	42	47	58	75	95	•	•	•	•	•	42	41	45	54	64
22	38	48	61	69	72	54	58	6	12	23	36	49	0.79	0.78	0.76	0.68	[illegible]	5	9	17	24	29
50	48	55	40	52	88	52	58	11	24	37	51	48	•	•	•	•	•	9	19	28	35	29
60	54	50	50	60	68	65	62	13	29	43	55	51	•	•	•	•	•	10	22	33	37	31
44	54	70	90	94	72	100	100	23	36	46	56	71	0.76	0.70	0.65	0.74	0.62	17	25	30	41	58
60	64	70	70	80	82	94	80	23	41	59	65	68	•	•	•	•	•	17	29	38	48	56
40	32	38	60	102	62	72	80	19	29	37	37	43	•	•	•	•	•	14	20	24	27	35
40	47	50	65	91	86	78	91	16	26	39	46	54	•	•	•	•	•	12	18	25	34	44
40	62	62	70	80	110	84	102	13	23	40	55	65	•	•	•	•	•	10	16	26	41	53
47	48	51	65	75	76	95	111	22	33	43	49	55	0.99	0.88	0.77	0.72	0.67	22	29	33	35	37
47	51	53	69	81	87	100	122	23	32	43	50	58	•	•	•	•	•	23	28	33	36	39
37	46	33	46	58	58	70	81	24	30	39	39	42	•	•	•	•	•	24	26	30	28	28
54	64	64	72	90	102	112	120	34	42	50	61	67	•	•	•	•	•	34	37	38	44	45
70	68	65	72	75	70	70	65	64	66	67	68	68	0.78••	0.80••	0.83••	0.75••	0.67••	50	53	56	51	46
65	42	55	52	48	45	62	68	58	64	56	54	50	•	•	•	•	•	45	51	46	40	34
60	52	60	62	58	58	84	98	66	66	62	57	58	•	•	•	•	•	51	53	51	43	39
60	65	60	68	68	68	68	88	78	71	67	62	64	•	•	•	•	•	61	57	56	46	43
52	52	45	55	52	52	45	62	79	68	55	50	51	•	•	•	•	•	62	54	46	38	34
55	55	60	75	90	90	85	110	63	62	57	57	63	•	•	•	•	•	49	50	47	43	42
60	72	85	95	115	125	135	162	51	52	59	72	84	•	•	•	•	•	40	42	49	54	56
62	68	72	82	92	100	118	138	72	63	61	67	74	•	•	•	•	•	56	50	51	50	50
70	60	55	65	70	80	90	105	88	77	67	62	60	•	•	•	•	•	69	62	56	46	40
50	50	55	60	65	80	65	85	82	73	58	52	55	•	•	•	•	•	64	58	48	39	37
50	50	55	60	65	80	65	85	82	73	58	52	55	•	•	•	•	•	64	58	48	39	37

Summary by 100-ft Stations

Station	Average Rating Cone Index 3- to 9-in. Layer			Average Speed, mph		
	Test 98	Test 99	Test 100	Test 98	Test 99	Test 100
0+00 to 1+00	10	10	52	5.6	5.2	2.3
1+00 to 2+00	26	24	51	2.1	1.8	1.9
2+00 to 3+00	17	21	54	2.0	1.8	2.1
3+00 to End	39	30	58	2.1	1.9	1.4

(Continued)

Table 2 (Concluded)

D. Maneuver-Speed Test (CH, Albemarle Lake)

Test No.	Vehicle Weight, lb	Location Between 10-sec Markers	Speed Data: 10-sec Distance ft	Speed fps	Speed mph	Cone Index at Depths, in.: 0	3	6	9	12	15	18	21	24	30	36	Avg Cone Index of Layers: 0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-	Re
																	Maneuver Markers 50 ft Apart					
101	3954	1 and 2	60	6.0	4.1	2	2	4	8	11	14	14	16	18	20	23	3	5	8	11	13	0.75*
		2 and 3	58	5.8	4.0	2	2	4	12	20	30	28	28	32	32	50	3	6	12	21	26	0.79
		3 and 4	29	2.9	3.0	2	3	5	16	23	28	28	35	32	37	40	3	8	15	22	26	0.70*
		4 and 5	56	5.6	3.8	21	15	24	36	51	52	54	73	87	87	106	20	25	37	46	[illegible]	0.64
		5 and 6	29	2.9	2.0	21	24	34	43	55	50	58	81	83	92	133	26	34	44	49	54	0.76
		6 and 7	29	2.9	2.0	10	11	27	42	53	60	75	87	75	74	79	16	27	41	52	63	0.76
		7 and 8	35	3.5	2.4	12	12	18	37	54	44	43	72	72	63	91	14	22	36	45	47	0.82*
		8 and 9	25	2.5	1.7	15	17	34	34	38	41	52	60	62	72	95	22	28	35	38	44	0.82*
		9 and 10	29	2.9	2.0	18	16	31	52	52	50	54	69	82	88	114	22	33	45	51	52	0.99
		10 and 11	21	2.1	1.4	22	20	41	42	48	51	59	86	96	100	121	28	34	44	47	53	0.83*
		11 and 12	20	2.0	1.4	67	73	58	37	39	46	43	48	56	80	90	66	56	45	41	43	0.83*
		12 and 13	18	1.8	1.2	65	100	75	43	45	45	48	47	48	67	77	87	73	54	44	46	0.78
		13 and 14	14	1.4	1.0	65	80	70	43	43	50	55	60	63	67	82	72	64	52	45	49	0.78*
		14 and 15	18	1.8	1.2	60	100	75	40	35	35	40	50	45	50	75	78	[illegible]	50	37	37	0.78*
102	3954	1 and 2†	34	3.4	2.3	2	2	3	5	6	10	14	17	18	22	30	2	3	5	7	10	0.25
		2 and 3	61	6.1	4.2	2	2	4	7	11	17	28	28	32	49	49	3	4	7	12	19	0.38
		3 and 4††	52	5.2	3.5	4	5	8	11	27	41	47	48	79	52	60	6	8	15	26	38	0.51*
		4 and 5	71	7.1	4.8	6	9	14	38	48	48	47	80	77	107	70	10	20	33	45	48	0.64
		5 and 6	53	5.3	3.6	10	10	23	50	63	58	75	110	100	98	110	14	28	45	57	65	0.65*
		6 and 7†	39	3.9	2.7	8	11	22	46	81	91	102	115	142	145	130	14	26	50	73	91	0.65*
		7 and 8	25	2.5	1.7	8	18	55	54	54	45	55	70	60	75	95	27	42	54	51	51	0.67*
		8 and 9†	58	5.8	4.0	33	27	34	52	56	61	76	82	91	96	102	31	38	47	56	64	0.78
		9 and 10	23	2.3	1.6	26	35	41	60	50	65	90	95	100	102	100	34	45	50	58	68	0.78
		10 and 11	28	2.8	1.9	18	29	30	50	60	75	90	105	115	110	120	26	36	47	62	75	0.78
		11 and 12	25	2.5	1.7	26	36	65	95	110	120	145	160	165	160	180	42	65	90	108	125	0.78
		12 and 13†	42	4.2	2.9	42	34	43	61	76	87	107	128	140	145	145	40	46	60	75	90	0.78*
		13 and 14	30	3.0	2.0	32	35	50	50	68	88	100	115	128	135	142	39	45	56	69	85	0.78*
																	Maneuver Markers 30 ft Apart					
103	3954	1 and 2	32	3.2	2.18	1	2	3	3	6	9	12	15	18	20	25	2	3	4	6	9	0.25*
		2 and 3	17	1.7	1.16	2	4	4	4	8	12	17	20	22	24	26	3	4	5	8	12	0.31*
		3 and 4	18	1.8	1.23	3	3	4	4	7	10	13	16	19	21	26	3	4	5	7	10	0.38*
		4 and 5	43	4.3	2.93	2	3	4	8	12	16	18	23	24	26	24	3	5	8	12	15	0.42*
		5 and 6	21	2.1	1.43	7	12	22	24	32	38	36	45	43	42	48	14	19	26	31	35	0.51
		6 and 7	14	1.4	0.95	12	22	38	35	50	54	48	42	58	55	62	24	32	41	46	51	0.57*
		7 and 8	41	4.1	2.80	10	11	21	36	45	62	70*	62	58	68	82	14	23	34	48	59*	0.64*
		8 and 9	42	4.2	2.86	8	7	10	23	35	43	52	50	75	80	90	8	13	23	34	43	0.64*
		9 and 10	37	3.7	2.52	8	8	12	42	45	55	52	72	90	70	80	9	21	33	47	51	0.65*
		10 and 11	28	2.8	1.91	10	10	12	40	58	65	70	118	100	100	108	11	21	37	54	64	0.65*
		11 and 12	18	1.8	1.23	25	20	25	35	45	60	60	70	85	100	135	23	27	35	47	55	0.65*
		12 and 13†	36	3.6	2.46	20	20	20	40	45	45	45	62	75	82	112	20	27	35	43	45	0.66*
		13 and 14	41	4.1	2.80	28	33	40	52	47	42	53	67	78	92	117	34	42	46	47	47	0.67*
		14 and 15	42	4.2	2.86	30	52	62	45	35	38	45	52	62	85	102	48	53	47	39	39	0.72*
		15 and 16	40	4.0	2.73	45	70	65	50	45	35	45	40	40	55	55	60	62	53	43	42	0.78*
		16 and 17	9	0.9	0.61	50	85	55	40	45	55	60	50	40	65	80	63	60	47	47	53	0.78*
		17 and 18	25	2.5	1.70	55	80	62	38	45	58	58	52	55	68	80	66	60	49	48	55	0.78*
		18 and 19	29	2.9	1.98	65	78	62	48	50	52	58	50	58	58	78	68	63	53	50	53	0.78*
		19 and 20	49	4.9	3.34	58	75	60	55	40	42	48	52	50	50	68	64	63	52	46	43	0.78*
		20 and 21	34	3.4	2.32	42	58	48	50	52	55	60	65	68	80	95	49	52	50	52	56	0.78*

Summary of 100-ft Stations, Test 101

Station	Distance, ft Along Path of Vehicle	Average Rating Cone Index 3- to 9-in. Layer	Average Speed, mp
0+00 to 1+00	110	5	3.64
1+00 to 2+00	107	14	2.75
2+00 to 3+00	104	20	1.61
3+00 to 4+00	104	41	1.58
4+00 to End	17	58	1.30

Note: No moisture content measured for test 102.

* Estimated from adjacent measured values.

** Moisture contents measured at approximate location indicated.

† Start of test; sp

†† Ditch across test

Table 2 (Concluded)

D. Maneuver-Speed Test (CH, Albemarle Lake)

t Depths, in.						Avg Cone Index of Layers					Remolding Index of Layers					Rating Cone Index of Layers					Moisture Content, % of Dry Weight of Layers			
5	18	21	24	30	36	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-18 in.	9-15 in.	12-18 in.	0-1 in.	0-6 in.	6-12 in.	12-18 in.
						Maneuver Markers 50 ft Apart																		
4	14	16	18	20	23	3	5	8	11	13	0.75*	0.75	0.75	0.70	0.65	2	4	6	8	8				
0	28	28	32	32	50	3	6	12	21	26	0.79	0.78	0.76	0.68	0.60	2	5	9	14	16	144.1**	145.6	80.6	77.2
8	28	35	32	37	40	3	8	15	22	26	0.70*	0.70	0.70	0.69	0.68	2	6	10	15	18				
2	54	73	87	87	106	20	25	37	46	52	0.64	0.66	0.68	0.72	0.76	13	16	25	33	40				
0	58	81	83	92	133	26	34	44	49	54	0.76	0.70	0.65	0.58	0.52	20	24	29	28	28				
0	75	87	75	74	79	16	27	41	52	63	0.76	0.70	0.65	0.74	0.82	12	19	27	38	52				
4	43	72	72	63	91	14	22	36	45	47	0.82*	0.76	0.71	0.72	0.74	11	17	26	32	35				
1	52	60	62	72	95	22	28	35	38	44	0.82*	0.76	0.71	0.72	0.74	18	21	25	27	32				
0	54	69	82	88	114	22	33	45	51	52	0.99	0.88	0.77	0.72	0.67	22	29	35	37	35				
1	59	86	96	100	121	28	34	44	47	53	0.83*	0.84	0.80	0.74	0.67	23	28	35	35	36				
6	43	48	56	80	90	66	56	45	41	43	0.83*	0.84	0.80	0.74	0.67	55	46	36	30	29	50.4**	47.9	64.3	45.8
5	48	47	48	67	77	87	73	54	44	46	0.78	0.80	0.83	0.75	0.67	68	58	45	33	31				
0	55	60	63	67	82	72	64	52	45	49	0.78*	0.80	0.83	0.75	0.67	56	51	43	34	33				
5	40	50	45	50	75	78	72	50	37	37	0.78*	0.80	0.83	0.75	0.67	61	56	42	28	25				
0	14	17	18	22	30	2	3	5	7	10	0.25	0.44	0.63	0.50	0.37	1	1	3	4	4				
7	28	28	32	49	49	3	4	7	12	19	0.38*	0.46	0.65	0.58	0.50	1	2	4	7	10				
1	47	48	79	52	60	6	8	15	26	38	0.51*	0.59	0.66	0.65	0.63	3	5	10	17	24				
8	47	80	77	107	70	10	20	33	45	48	0.64	0.66	0.68	0.72	0.76	6	13	22	32	36				
8	75	110	100	98	110	14	28	45	57	65	0.65*	0.67	0.69	0.72	0.75	9	19	31	41	49				
1	102	115	142	145	130	14	26	50	73	91	0.65*	0.67	0.69	0.72	0.75	9	17	34	52	68				
5	55	70	60	75	95	27	42	54	51	51	0.67*	0.69	0.71	0.73	0.74	18	29	38	37	38				
1	76	82	91	96	102	31	38	47	56	64	0.78	0.80	0.83	0.75	0.67	24	30	39	42	43				
5	90	95	100	102	100	34	45	50	58	68	0.78	0.80	0.83	0.75	0.67	26	36	42	44	46				
5	90	105	115	110	120	26	36	47	62	75	0.78	0.80	0.83	0.75	0.67	20	29	39	46	50				
0	145	160	165	160	180	42	65	90	108	125	0.78	0.80	0.83	0.75	0.67	33	52	75	81	84				
7	107	128	140	145	145	40	46	60	75	90	0.78*	0.80	0.83	0.75	0.67	31	37	50	56	60				
8	100	115	128	135	142	39	45	56	69	85	0.78*	0.80	0.83	0.75	0.67	30	36	46	52	57				
						Maneuver Markers 30 ft Apart																		
9	12	15	18	20	25	2	3	4	6	9	0.25*	0.44	0.63	0.50	0.37	1	1	2	2	2	123.4**,‡‡	141.7	102.0	104.1
2	17	20	22	24	26	3	4	5	8	12	0.31*	0.44	0.64	0.54	0.42	1	2	3	4	5	---	---	---	---
0	13	16	19	21	26	3	4	5	7	10	0.38*	0.46	0.65	0.58	0.50	1	2	3	4	5	---	---	---	---
6	18	23	24	26	24	3	5	8	12	15	0.42*	0.53	0.66	0.61	0.55	1	3	5	7	8	---	---	---	---
8	36	45	43	42	48	14	19	26	31	35	0.51*	0.59	0.66	0.65	0.63	7	11	17	20	22	---	---	---	---
4	48	42	58	55	62	24	32	41	46	51	0.57*	0.62	0.67	0.68	0.69	14	20	28	31	35	---	---	---	---
2	70*	62	58	68	82	14	23	34	48	59*	0.64*	0.66	0.68	0.72	0.76	9	15	23	34	45	---	---	---	---
3	52	50	75	80	90	8	13	23	34	43	0.64*	0.67	0.69	0.72	0.76	5	9	16	24	33	---	---	---	---
5	52	72	90	70	80	9	21	33	47	51	0.65*	0.67	0.69	0.72	0.75	6	14	23	34	38	79.1**	89.3	58.7	37.8
5	70	118	100	100	108	11	21	37	54	64	0.65*	0.67	0.69	0.72	0.75	7	14	26	39	48	---	---	---	---
0	60	70	85	100	135	23	27	35	47	55	0.65*	0.67	0.69	0.72	0.75	15	18	24	34	41	---	---	---	---
5	45	62	75	82	112	20	27	35	43	45	0.66*	0.68	0.70	0.73	0.74	13	18	24	31	33	---	---	---	---
2	53	67	78	92	117	34	42	46	47	47	0.67*	0.69	0.71	0.73	0.74	23	29	33	34	35	---	---	---	---
8	45	52	62	85	102	48	53	47	39	39	0.72*	0.74	0.77	0.74	0.70	34	39	36	29	27	---	---	---	---
5	45	40	40	55	55	60	62	53	43	42	0.78*	0.80	0.83	0.75	0.67	47	50	44	32	28	---	---	---	---
5	60	50	40	65	80	63	60	47	47	53	0.78*	0.80	0.83	0.75	0.67	49	48	39	35	36	---	---	---	---
8	58	52	55	68	80	66	60	49	48	55	0.78*	0.80	0.83	0.75	0.67	52	48	41	36	37	- -	---	---	---
[illegible]	58	50	58	58	78	68	63	53	50	53	0.78*	0.80	0.83	0.75	0.67	53	50	44	38	36	44.6**	47.0	62.0	43.1
[illegible]	48	52	50	50	68	64	63	52	46	43	0.78*	0.80	0.83	0.75	0.67	50	50	43	34	29	---	---	---	---
[illegible]	60	65	68	80	95	49	52	50	52	56	0.78*	0.80	0.83	0.75	0.67	38	42	42	39	38	---	---	---	---

Summary of 100-ft Stations, Test 101

Station	Distance, ft Along Path of Vehicle	Average Rating Cone Index 3- to 9-in. Layer	Average Speed, mph
0+00 to 1+00	110	5	3.64
1+00 to 2+00	107	14	2.75
2+00 to 3+00	104	20	1.61
3+00 to 4+00	104	41	1.58
4+00 to End	17	58	1.30

nt measured values.
ured at approximate location indicated.

† Start of test; speed not used in analysis.
†† Ditch across test lane; speed not used in analysis.

‡ Lateral movement employed during 10-sec interval.
‡‡ Test lane under approximately 2 in. of water.

(4 of 4 sheets)

Test No.	Vehicle Weight lb	Immobilization Yes/No	Immobilization Pass No.	Data Pass No.	Cone Index at Depths, in. 0	3	6	9	12	15	18	21	24	30	36	Avg Cone Index of Layers 0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	Remolding Index of Layers 0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.
67	3954	Yes	2*	0	26	11	12	14	16	20	22	27	42	49	46	16	12	14	17	19	0.78	0.73	0.68	0.69	0.70
				1	17	6	7	11	14	20	28	42	46	46	56	10	8	11	15	21					
				10	6	6	9	14	19	30	42	46	47	50	60+	7	10	14	21	30					
				23	4	4	8	14	20	42	46	50	48	54+	65+	5	9	14	25	36					
68	3954	Yes	2*	0	36	20	16	19	22	26	30	34	49	66+	57+	24	18	19	22	26	0.64	0.47	0.30	0.44	0.57
				1	34	16	10	15	20	24	30	41	54	61	66	20	14	15	20	25					
				5	26	10	8	12	18	25	36	51	57	54	68+	15	10	13	18	26					
69	2860	Yes	8*	0	40	24	18	20	24	28	33	42	56	60	66	27	21	21	24	28	0.73	0.61	0.49	0.48	0.46
				1	36	18	12	16	22	26	36	54	62	70	70+	22	15	17	21	28					
				9	26	13	10	16	22	30	46	60	68+	74+	80+	16	13	16	23	33					
				37	5	7	12	23	35	44	54	54	58	76+	85+	8	14	23	34	44					
				41	6	5	8	16	22	30	46	56	63+	63+	82+	6	10	15	23	33					
				47	9	6	10	16	22	36	50	62+	68+	71+	90+	8	11	16	25	36					
70	3954	Yes	2*	0	34	18	12	17	20	24	30	41	56	66	64	21	16	16	20	25	0.66	0.70	0.75	0.78	0.82
				1	41	13	10	14	18	24	30	48	57	60+	66+	21	12	14	19	24					
72	3954	Yes**	1	0	14	6	8	10	12	16	20	34	42	40	46	9	8	10	13	16	0.65	0.70	0.75	0.56	0.37
80	3954	Yes	40*	0	27	12	10	12	16	22	25	34	46	54	52	16	11	13	17	21	0.82	0.73	0.64	0.62	0.60
				1	28	11	8	16	22	29	36	60	70	68+	70+	16	12	15	22	29					
				10	10	7	6	8	14	18	29	35	41	35	48	8	7	9	13	20					
				20	4	6	8	13	18	27	44	52	55	56	70+	6	9	13	19	30					
				42	4	5	8	15	26	42	52	50	49	62+	72+	6	9	16	28	40					

* See remarks.
** Rotors turned in this test, not in others.

Table 3

Tests on Fine-Grained Soil (CH, Centennial Lake), Marsh Screw Amphibian

A. Repetitive-Pass Tests on Level Soil (CH, Centennial Lake)

		Avg Cone Index of Layers					Remolding Index of Layers					Rating Cone Index of Layers					Moisture Content, % of Dry Weight of Layers				Dry Density, lb/cu ft, of Layers			Avg Rut Depth	
30	36	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-1 in.	0-6 in.	6-12 in.	12-18 in.	0-6 in.	6-12 in.	12-18 in.	in.	
49	46	16	12	14	17	19	0.78	0.73	0.68	0.69	0.70	12	9	10	12	13	72.9	80.2	85.6	69.5	51.3	48.7	54.0	---	Vehicle turn r 0+00 t circle comple until verse.
46	56	10	8	11	15	21											--							4.4	
50	60+	7	10	14	21	30											85.6							8.0	
54+	65+	5	9	14	25	36											--							3.0	
66+	57+	24	18	19	22	26	0.64	0.47	0.30	0.44	0.57	15	8	6	10	15	60.6	69.8	83.4	93.0	55.4	49.6	46.3	---	Vehicle turn r five p verse)
61	66	20	14	15	20	25											60.1							1.7	
54	68+	15	10	13	18	26											65.5							4.3	
60	66	27	21	21	24	28	0.73	0.61	0.49	0.48	0.46	20	13	10	12	13	60.4	70.5	78.8	81.7	54.9	52.2	50.1	---	On 8th turn r circle Circli pass v traffi ward. this t
70	70+	22	15	17	21	28											--							0.9	
74+	80+	16	13	16	23	33											67.5							2.9	
76+	85+	8	14	23	34	44											70.6							---	
63+	82+	6	10	15	23	33											--							---	
71+	90+	8	11	16	25	36											74.7							8.6	
66	64	21	16	16	20	25	0.66	0.70	0.75	0.78	0.82	14	11	12	16	20	61.2	73.6	84.8	86.6	54.7	50.0	48.2	---	Vehicle cause Vehicle
60+	66+	21	12	14	19	24											--							1.4	
40	46	9	8	10	13	16	0.65	0.70	0.75	0.56	0.37	6	6	8	7	6	95.8	--	--	--	--	--	--	---	Vehicle Vehicle
54	52	16	11	13	17	21	0.82	0.73	0.64	0.62	0.60	13	8	8	10	13	69.3	74.8	80.4	82.1	53.9	52.0	51.0	---	This test first t due to pass. power t going f immobil
68+	70+	16	12	15	22	29											64.9							1.4	
35	48	8	7	9	13	20											71.4							3.6	
56	70+	6	9	13	19	30											74.6							6.1	
62+	72+	6	9	16	28	40											76.5 (After 41 passes)							9.0	

(Continued)

ble 3

ntennial Lake), Marsh Screw Amphibian

Level Soil (CH, Centennial Lake)

ne Index of Layers 6-12 in.	9-15 in.	12-18 in.	Moisture Content, % of Dry Weight of Layers 0-1 in.	0-6 in.	6-12 in.	12-18 in.	Dry Density, lb/cu ft, of Layers 0-6 in.	6-12 in.	12-18 in.	Avg Rut Depth in.	Remarks
10	12	13	72.9	80.2	85.6	69.5	51.3	48.7	54.0	---	Vehicle could not travel in reverse on 2d pass due to insufficient power to turn rotors, but could travel forward. Vehicle reentered test lane at sta 0+00 traveling forward and completed pass 2; could not back up. Vehicle circled around and reentered test lane at sta 0+00 traveling forward and completed pass 3. After completing pass 3 vehicle traveled back and forth until 23 passes were completed. Vehicle immobilized on 24th pass in reverse. Completed 26th pass with high rotor slip. Test halted
			--							4.4	
			85.6							8.0	
			--							8.0	
6	10	15	60.6	69.8	83.4	93.0	55.4	49.6	46.3	---	Vehicle could not travel in reverse on 2d pass due to insufficient power to turn rotors. Five passes completed with vehicle traveling forward on all five passes. On 6th pass vehicle could not turn rotors (forward or reverse) due to insufficient power. Test stopped on 6th pass
			60.1							1.7	
			65.5							4.3	
10	12	13	60.4	70.5	78.8	81.7	54.9	52.2	50.1	---	On 8th pass vehicle could not travel in reverse due to insufficient power to turn rotors; could travel forward. Vehicle pulled out of test lane, circled around, reentered test lane at sta 0+00, and completed 8th pass. Circling and reentering procedure continued through 13th pass. On 14th pass vehicle able to travel in reverse. After 13th pass vehicle continued traffic back and forth until 47th pass; vehicle immobilized traveling forward. A layer of mud from 1 to 2 in. thick covered the rotors throughout this test
			--							0.9	
			67.5							2.9	
			70.6							---	
			--							---	
			74.7							8.6	
12	16	20	61.2	73.6	84.8	86.6	54.7	50.0	48.2	---	Vehicle completed 1st pass. After attempting 2d pass test was stopped because vehicle could not turn rotors in reverse due to insufficient power. Vehicle was able to pull out of test lane moving laterally
			--							1.4	
8	7	6	95.8	--	--	--	--	--	--	---	Vehicle immobilized on the 1st pass going forward. Undercarriage dragging. Vehicle unable to move forward or backward. Rotors were turning
8	10	13	69.3	74.8	80.4	82.1	53.9	52.0	51.0	---	This test lane was sprinkled with water prior to test. Vehicle completed first three passes with ease. Began to experience difficulty on 4th pass due to insufficient power to turn rotors. Vehicle began to drag on 35th pass. Vehicle unable to move in reverse on 40th pass due to insufficient power to turn rotors. Pulled self forward out of test lane and reentered going forward. Extreme difficulty experienced in forward gear. Vehicle immobilized on 42nd pass in forward gear with undercarriage dragging
			64.9							1.4	
			71.4							3.6	
			74.6							6.1	
			76.5 (After 41 passes)							9.0	

nued)

3

B. Towing Forc

Test No.	Vehicle Weight, lb	Towing Force lb	Towing Force % Test Weight	Speed mph	Slip %	Cone Index at Depths, in. 0	3	6	9	12	15	18	21	24	30	36	Avg Cone 0-6 in.	Avg Cone 3-9 in.
74A	3954	930	23.4	0.8	14	36	16	19	22	24	30	36	41	46	56	56	24	19
						24*	12	10	14	20	24	30	50	59	59	66		
74B**	3954	1150	29.0	0.5	35	34	18	18	22	24	29	34	42	50	63	75	23	19
						19*	10	12	16	22	28	42	52	60	69	68		
76**	3954	589	14.9	0.6	36	23	10	10	14	16	22	28	35	54	67	76	14	11
						3*	5	9	13	22	34	45	52	54	55	58		
77A†	3954	980	24.7	---	--	31	14	15	20	26	30	41	58	66	74	72	20	16
77B†	3954	1500	37.8	---	--	31	16	17	22	28	35	54	68	70	75+	74+	21	18
77C†	3954	1850	46.6	---	--	36	18	16	20	26	32	44	56	76	77	74	23	18
78A‡	3954	--	--	---	--	38	18	14	17	23	28	37	42	50	65	80	23	16
78B**	3954	860	21.7	0.5	10	58	26	22	26	30	34	38	40	46	58	71	35	25
78C**	3954	860	21.7	0.6	19	46	36	32	30	34	38	44	52	63	74	88	38	33
78D**	3954	1440	35.5	0.5	22	51	37	40	40	44	48	53	66	76	86+	94+	43	39
79A**	3954	610	15.4	0.5	14	129	96	76	72	68	68	62	72	85	98	84	100	81
79B	3954	1130	32.0	0.2	24	122	96	78	82	78	76	74	79	90	112	94	99	85
79C	3954	1030	26 0	0.3	15	89	72	66	62	58	56	59	70	79	78	73	76	67
81A**	3954	445	11.2	0.5	7	126	100	80	67	66	65	69	73	79	88	98	102	82
81B**	3954	580	14.6	0.5	2	128	108	86	74	74	76	80	86	93	106	118	107	89
82A	3954	5[illegible]0	13.1	0.9	4	94	126	116	102	99	80	87	90	67	102	131	112	115
82B	3954	650	16.4	1.0	6	114	112	132	135	140	148	166	184	198	187	186+	119	126
82C**	3954	1010	25.4	0.6	2	102	116	140	140	130	126	127	126	134	156	186	119	132
82D	3954	1560	39.3	0.4	19	118	128	144	138	130	118	131	138	148	166	184	130	137
83A**	3954	440	11.1	0.6	8	84	168	172+	169+	154	116	100	88	76	76	66	141+	170+
83B**	3954	600	15.1	0.6	14	94	132	120	126	104	94	92	90	62	46	51	115	126
83C	3954	800	20.2	0.2	19	86	148	156	148	126	108	96	91	83	54	54	130	151
84A**	3954	450	11.3	0.5	14	75	153	126	129	99	98	101	93	82	100	61	118	136
84B**	3954	800	20.2	0.6	2	100	154	149	189	104	97	104	102	78	83	60	134	164

Note: Tests underlined were run on bare area; tests not underlined were run on grass-covered area.
- * Second line cone index taken after one pass.
- ** Used in maximum towing force tests analysis.
- † Vehicle traveling laterally.
- †† Values assumed to be same as preceding listed value.
- ‡ No towing force data obtained.
- ‡‡ Remolding indexes from tests in adjacent areas.
- § Soil too firm to perform remolding test; remolding index of 1.00 assumed.

Table 3 (Concluded)

B. Towing Force Tests on Level Soil (CH, Centennial Lake)

at Depths, in.						Avg Cone Index of Layers					Remolding Index of Layers					Rating Cone Index of Layers				
15	18	21	24	30	36	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.
30	36	41	46	56	56	24	19	22	25	30	0.60	0.61	0.62	0.56	0.51	14	12	14	14	15
24	30	50	59	59	66															
29	34	42	50	63	75	23	19	21	25	29	0.60	0.61	0.62	0.56	0.51	14	12	13	14	15
28	42	52	60	69	68															
22	28	35	54	67	76	14	11	13	17	22	0.86	0 66	0.45	0.50	0.56	12	7	6	8	12
34	45	52	54	55	58															
30	41	58	66	74	72	20	16	20	25	32	0.76	0.64	0.52	0.64	0.77	15	10	10	16	25
35	54	68	70	75+	74+	21	18	22	28	39	††	††	††	††	††	16	12	11	18	30
32	44	56	76	77	74	23	18	21	26	34	††	††	††	††	††	17	12	11	17	26
28	37	42	50	65	80	23	16	18	23	29	0.70‡‡	0.70‡‡	0.70‡‡	0.70‡‡	0.70‡‡	16	11	13	16	20
34	38	40	46	58	71	35	25	26	30	34	††	††	††	††	††	24	18	18	21	24
38	44	52	63	74	88	38	33	32	34	38	††	††	††	††	††	27	23	22	24	27
48	53	66	76	86+	94+	43	39	41	44	48	††	††	††	††	††	30	27	29	31	34
68	62	72	85	98	84	100	81	72	69	66	0.80‡‡	0.80‡‡	0.80‡‡	0.80‡‡	0.80‡‡	80	65	58	55	53
76	74	79	90	112	94	99	85	79	79	76	††	††	††	††	††	79	68	63	63	61
56	59	70	79	78	73	76	67	62	59	58	††	††	††	††	††	61	54	50	47	46
65	69	73	79	88	98	102	82	71	66	67	0.96	0.86	0.77	0.74	0.72	98	71	55	49	48
76	80	86	93	106	118	107	89	78	75	77	††	††	††	††	††	103	77	60	56	55
80	87	90	87	102	131	112	115	106	94	89	††	††	††	††	††	108	99	82	70	64
148	166	184	198	187	186+	119	126	136	141	151	††	††	††	††	††	114	108	105	104	109
126	127	126	134	156	186	119	132	137	132	128	††	††	††	††	††	114	114	105	98	92
118	131	138	148	166	184	130	137	137	129	126	††	††	††	††	††	125	118	105	95	91
116	100	88	76	76	66	141+	170+	165+	146+	123	1.00§	1.00§	1.00§	1.00§	0.96	141+	170+	165+	146+	118
94	92	90	62	46	51	115	126	117	108	97	††	††	††	††	††	115	126	117	108	93
108	96	91	83	54	54	130	151	143	127	110	††	††	††	††	††	130	151	143	127	106
98	101	93	82	100	61	118	136	118	109	99	††	††	††	††	††	118	136	118	109	95
97	104	102	78	83	60	134	164	147	130	102	††	††	††	††	††	134	164	147	130	98

-covered area.

...oncluded)

...l Soil (CH, Centennial Lake)

...s	Remolding Index of Layers					Rating Cone Index of Layers					Moisture Content, % of Dry Weight of Layers				Dry Density, lb/cu ft, of Layers		
12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-1 in.	0-6 in.	6-12 in.	12-18 in.	0-6 in.	6-12 in.	12-18 in.
30	0.60	0.61	0.62	0.56	0.51	14	12	14	14	15	56.5	63.2	89.6	86.2	60.2	47.2	48.2
29	0.60	0.61	0.62	0.56	0.51	14	12	13	14	15	--	--	--	--	--	--	--
22	0.86	0.66	0.45	0.50	0.56	12	7	6	8	12	59.6	67.1	91.1	88.2	57.5	45.8	47.8
32	0.76	0.64	0.52	0.64	0.77	15	10	10	16	25	53.8	53.7	85.0	62.4	62.2	48.9	57.4
39	††	††	††	††	††	16	12	11	18	30	53.8	53.7	85.0	62.4	62.2	48.9	57.4
35	††	††	††	††	††	17	12	11	17	26	53.8	53.7	85.0	62.4	62.2	48.9	57.4
29	0.70‡‡	0.70‡‡	0.70‡‡	0.70‡‡	0.70‡‡	16	11	13	16	20	52.5	59.4	82.3	--	60.2	50.5	--
34	††	††	††	††	††	24	18	18	21	24	49.7	55.6	82.0	--	64.8	50.5	--
38	††	††	††	††	††	27	23	22	24	27	46.8	53.2	74.2	--	67.0	54.8	--
48	††	††	††	††	††	30	27	29	31	34	44.6	51.2	70.4	--	67.8	57.4	--
66	0.80‡‡	0.80‡‡	0.80‡‡	0.80‡‡	0.80‡‡	80	65	58	55	53	35.5	40.1	55.9	--	77.6	62.1	--
76	††	††	††	††	††	79	68	63	63	61	--	--	--	--	--	--	--
58	††	††	††	††	††	61	54	50	47	46	--	--	--	--	--	--	--
67	0.96	0.86	0.77	0.74	0.72	98	71	55	49	48	19.7	41.0	56.6	--	71.4	65.9	--
77	††	††	††	††	††	103	77	60	56	55	††	††	††	--	††	††	--
89	††	††	††	††	††	108	99	82	70	64	26.1	39.5	39.4	--	79.0	79.4	--
151	††	††	††	††	††	114	106	105	104	109	††	††	††	--	††	††	--
128	††	††	††	††	††	114	114	105	98	92	††	††	††	--	††	††	--
126	††	††	††	††	††	125	118	105	95	91	††	††	††	--	††	††	--
123	1.00§	1.00§	1.00§	1.00§	0.96	141+	170+	165+	146+	118	15.0	32.1	37.4	--	60.8	82.8	--
97	††	††	††	††	††	115	126	117	108	93	††	††	††	--	††	††	--
110	††	††	††	††	††	130	151	143	127	106	††	††	††	--	††	††	--
99	††	††	††	††	††	118	136	118	109	95	††	††	††	--	††	††	--
102	††	††	††	††	††	134	164	147	130	98	††	††	††	--	††	††	--

3

(2 of 2 sheets)

Table 4

Tests in Fine-Grained Soil (ML, Bottomland Silt), Marsh Screw Amphibian and Weasel

A. Towing Force Tests, Marsh Screw Amphibian

Test No.	Vehicle Weight lb	Towing Force lb	Towing Force %	Speed mph	Cone Index at Depths, in. 0	3	6	9	12	15	18	21	24	30	36	Avg Cone Index of Layers 0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	Moisture Content, % of Dry Weight 0-1 in.	0-6 in.	6-12 in.	Remarks
95	3954	930	23.4	0.6	182	635+	635+	542+	570+	610+	612+	--	--	--	--	484	604	582	574	597	11.2	22.0	17.9	Area covered with grass 12 to 30 in. high with underlying mat of Bermuda
96	3954	880	22.2	0.1	245	455	490	630	365	385	338	--	--	--	--	397	525	495	460	363	14.1	17.9	19.4	Area covered with grass 12 to 18 in. high. No underlying mat

B. Obstacle Tests (Simulated Rice Field), Marsh Screw Amphibian and Weasel

Test No.	Vehicle Weight lb	Time to Cross Dike, sec 1	2	3	4	Total Time sec	Avg Cone Index Between Dikes for 3- to 9-in. Layers 0 & 1	1 & 2	2 & 3	3 & 4	4 & End	Water Depth in.	Accelerometer Value on Dikes, g Vertical 1	Vertical 2	Vertical 3	Vertical 4	Longitudinal 1	Longitudinal 2	Longitudinal 3	Longitudinal 4	Lateral 1	Lateral 2	Lateral 3	Lateral 4	Remarks
												Marsh Screw													
86	3954	8.2	39.9	5.0	13.3	86	103	175	167	167	142	8	1.24	2.30	1.75	1.41	1.32	2.41	1.96	2.88	0.68	1.54	1.29	1.04	Engine stalled on dike 2
88	3954	12.4	23.6	6.6	10.1	70	185+	196+	222+	190	147	8	2.04	2.44	1.48	1.56	1.87	0.76	1.10	1.46	1.68	1.40	1.52	1.82	Engine stalled on dikes 1 and 2
Average of two tests		10.3	31.7	5.5	11.7	78	144	185	195+	179	144	8	1.64	2.37	1.62	1.49	1.60	1.58	1.53	2.17	1.18	1.47	1.41	1.43	
												M29C Weasel													
85	4960	2.0	4.2	5.0	4.7	28	98	143	159	178	156	8	1.33	1.03	0.93	1.11	1.18	1.07	0.75	0.94	0.96	0.59	0.44	0.46	
Average of three tests							129	171	183	178	148														

Table 5

Tests on Fine-Grained Soil (CH, WES)

Repetitive-Pass Test on Prepared Buckshot Clay, Marsh Screw Amphibian

Test No.	Vehicle Weight lb	Immobilization Yes/No	Immobilization Pass No.	Data Pass No.	Cone Index at Depths, in. 0	3	6	9	12	15	18	21	24	30	36	Moisture Content, % 0-3 in.	Moisture Content, % 3-6 in.	Dry Density % Dry Wt 0-3 in.	Dry Density % Dry Wt 3-6 in.	Remarks
97	3954	(See Remarks)		0	22	72	300+	274+	256+	285+	290+	30C+	--	--	--	30.9	19.6	82.7	84.3	Vehicle unable to complete 1st pass because of insufficient power to turn rotors. Soil surface beneath vehicle and soil area in front of vehicle wetted with water. Vehicle was then able to travel forward and backward with ease through wetted area. Unable to travel in unwetted area. Buildup of soil on rotors wiped off by firm dry soil below 6 in.
				1												47.6*				
				1												39.9**				

Note: 5 in. soft soil over dry firm soil. Unable to obtain sample to perform remolding test.
* Moisture content, 0 to 1/4 in., in ruts of wetted area.
** Moisture content, 0 to 1/4 in., in ruts of unwetted area.

Test No.	Vehicle Weight lb	Immobilization Yes/No	Immobilization Pass	Data Pass No.	Cone Index at Depths, in. 0	3	6	9	12	15	18	21	24	30	36	Avg Cone Index of Layers 0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-1 in.
3	4960	Yes	4	0	3	4	5	8	12	16	24	22	24	29	34	4	6	8	12	17
10	4960	Yes	1	0	2	4	6	11	17	22	28	26	26	37	53	4	7	11	17	22
71	4960	Yes	19	0	25	9	10	14	17	22	26	36	50	54+	56+	15	11	14	18	22
				1	20	8	10	14	18	24	30	49	54	60	67+	13	11	14	19	24
				12	20	6	8	12	18	26	40	54	61	61	78+	11	9	13	19	28
				18	15	8	10	14	17	32	44	68+	68+	62+	70+	11	11	14	21	31
				19	25	8	11	14	18	24	28	48	59	72	72+	15	11	14	19	23

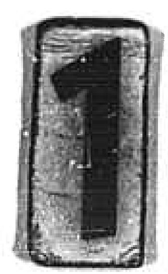


Table 6

Tests on Fine-Grained Soils (CH, Albemarle Lake and Centennial Lake), M29C Weasel

A. Repetitive-Pass Tests on Level Soil

t Depths, in.					Avg Cone Index of Layers					Remolding Index of Layers					Rating Cone Index of Layers					Moi of Dr
18	21	24	30	36	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-1 in.
												Albemarle Lake								
24	22	24	29	34	4	6	8	12	17	0.71	0.68	0.64	0.60	0.56	3	4	5	7	10	--
28	26	26	37	53	4	7	11	17	22	0.80	0.78	0.75	0.68	0.61	3	5	8	12	13	--
												Centennial Lake								
26	36	50	54+	56+	15	11	14	18	22	0.77	0.72	0.68	0.64	0.61	12	8	10	12	13	69.4
30	49	54	60	67+	13	11	14	19	24											
40	54	61	61	78+	11	9	13	19	28											
44	68+	68+	62+	70+	11	11	14	21	31											
28	48	59	72	72+	15	11	14	19	23											

2

(Continued)

d Centennial Lake), M29C Weasel

evel Soil

Rating Cone Index of Layers 0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	Moisture Content, % of Dry Weight of Layers 0-1 in.	0-6 in.	6-12 in.	12-18 in.	Dry Density, lb/cu ft, of Layers 0-6 in.	6-12 in.	12-18 in.	Avg Rut Depth in.	Remarks
3	4	5	7	10	--	148.8	102.5	77.4	32.6	43.9	54.4	---	Test run parallel to test 4 of Marsh Screw Amphibian. (Essentially same soil conditions.) Vehicle completed three passes without difficulty; was immobilized in reverse on 4th pass. Tracks were spun
3	5	8	12	13	--	167.9	76.6	69.5	28.2	55.1	58.9	---	The vehicle was immobilized trying to pull into a test lane; tracks were spun. Data shown were collected in the vicinity of the immobilized vehicle
12	8	10	12	13	69.4	85.5	85.1	95.6	49.9	49.8	45.1	--- 2.2 4.6 7.7 ---	Vehicle began to drag along entire test lane after five passes. Vehicle immobilized on 19th pass going forward between sta 0+10 and 0+20. Vehicle unable to move forward or backward. Tracks were spun

3

(1 of 2 sheets)

B. T

Test No.	Vehicle Weight lb	Towing Force lb	Towing Force % Test Weight	Speed mph	Slip %	Cone Index at Depths, in. 0	3	6	9	12	15	18	24	30	36
239	4960	2900	58	2.1	17.2	60	64	59	50	58	70	54	44	41	57
240	4960	3400	68	1.9	20.5	56	63	52	52	51	71	61	52	48	63
241	4960	3600	73	1.7	28.0	56	60	66	61	52	78	70	56	50	62
242	4960	3800	77	1.4	39.2	62	68	64	58	51	72	71	58	50	64
243	4960	4000	81	1.1	52.4	65	84	83	71	60	81	82	58	47	51
244	4960	3600	73	1.9	21.0	68	66	69	58	57	75	79+	56	50	55
245	4960	4200	85	1.5	35.2	59	79+	75+	56	67+	84+	66+	51	50	47
246	4960	2900	58	2.1	11.9	57	82	84+	58	64	86	67+	58	57	42

* Remolding index values estimated from adjacent tests.

Table 6 (Concluded)

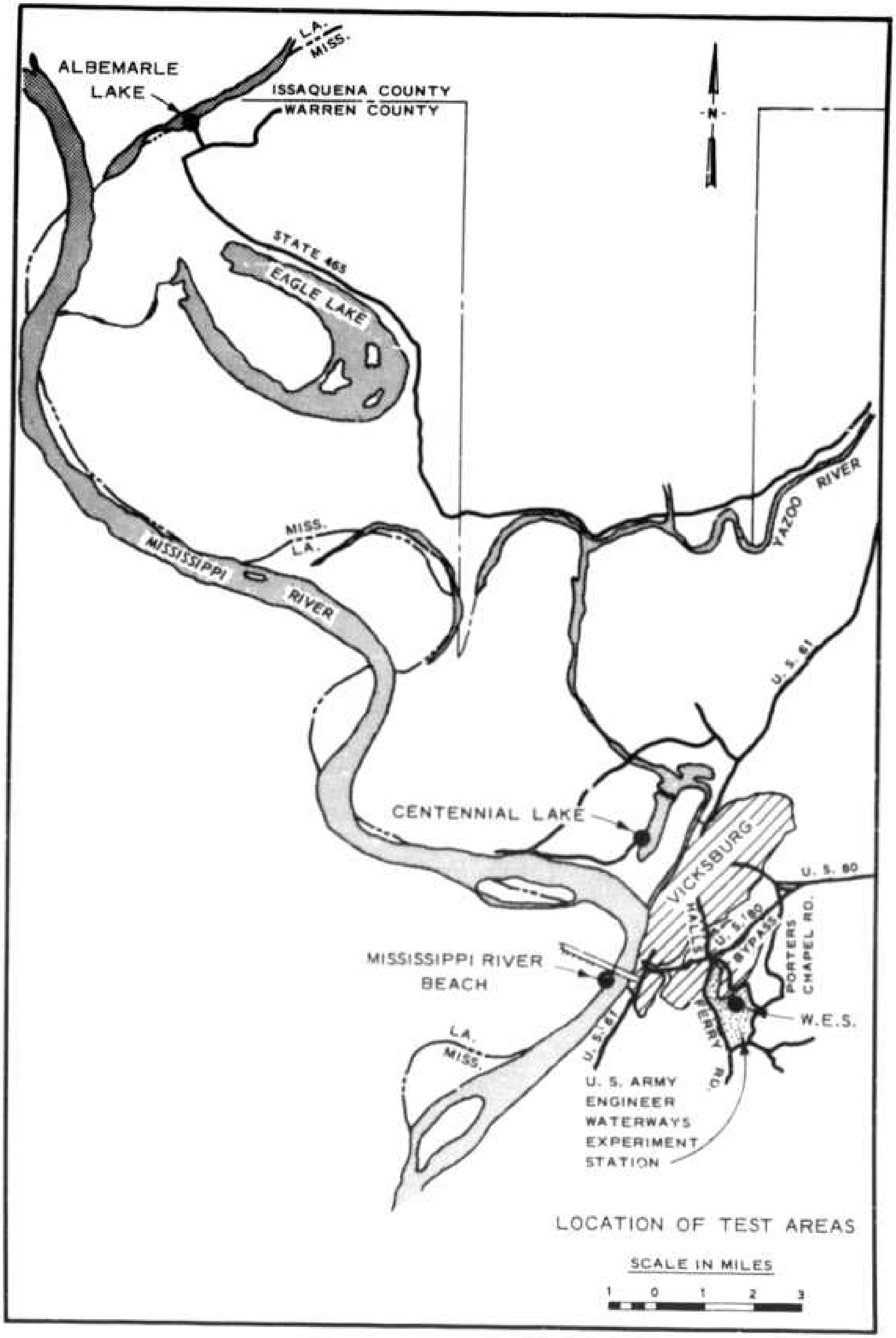
B. Towing Force Tests on Level Soil (Centennial Lake)

...ex at Depths, in.						Avg Cone Index of Layers					Remolding Index of Layers			Rating Cone Index of Lay...	
12	15	18	24	30	36	0-6 in.	3-9 in.	6-12 in.	9-15 in.	12-18 in.	0-6 in.	3-9 in.	6-12 in.	0-6 in.	3-9 in.
58	70	54	44	41	57	61	58	56	59	61	0.78*	0.80*	0.82*	48	46
51	71	61	52	48	63	57	56	52	58	61	0.78	0.80	0.82	44	45
52	78	70	56	50	62	61	62	60	64	67	0.74*	0.75*	0.77*	45	45
51	72	71	58	50	64	65	63	58	60	65	0.74	0.75	0.77	48	47
60	81	82	58	47	51	77	79	71	71	74	0.88*	0.78*	0.74*	68	62
57	75	79+	56	50	55	68	64	61	63	70+	0.74*	0.75*	0.77*	50	48
67+	84+	66+	51	50	47	71+	70+	66+	69+	72+	0.88	0.78	0.74	62	55
64	86	67+	58	57	42	74+	75+	69+	69	72+	0.88*	0.78*	0.74*	65	58

Centennial Lake)

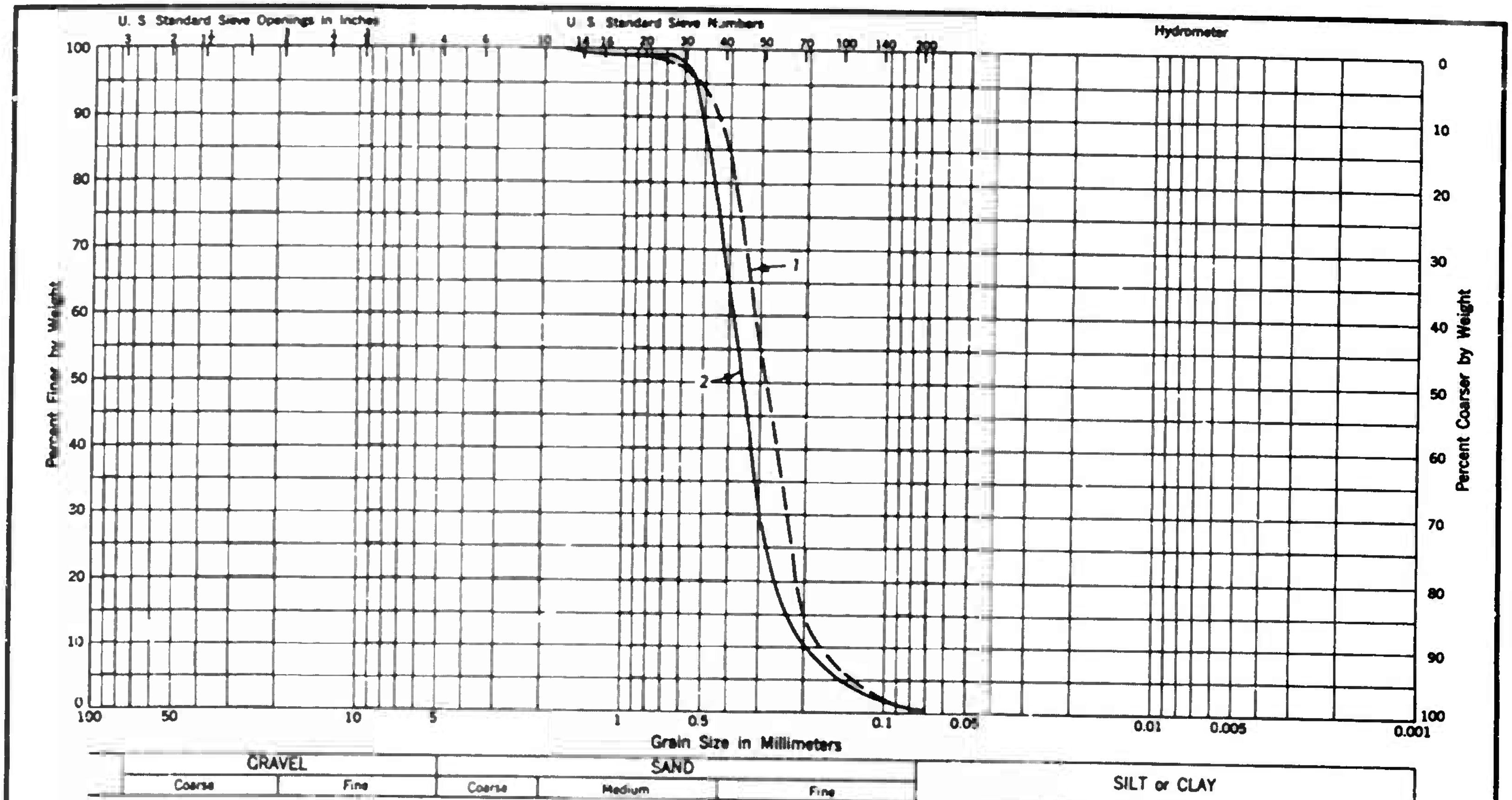
Remolding Index of Layers			Rating Cone Index of Layers			Moisture Content, % of Dry Weight of Layers				Dry Density, lb/cu ft of Layers			
0-6 in.	3-9 in.	6-12 in.	0-6 in.	3-9 in.	6-12 in.	0-3 in.	3-6 in.	6-9 in.	9-12 in.	0-3 in.	3-6 in.	6-9 in.	9-12 in.
0.78*	0.80*	0.82*	48	46	46	--	--	--	--	--	--	--	--
0.78	0.80	0.82	44	45	43	38.5	47.3	46.6	49.4	76.4	67.4	69.2	--
0.74*	0.75*	0.77*	45	46	46	--	--	--	--	--	--	--	--
0.74	0.75	0.77	48	47	45	41.7	49.1	54.7	53.3	69.3	60.9	60.7	65.6
0.88*	0.78*	0.74*	68	62	52	--	--	--	--	--	--	--	--
0.74*	0.75*	0.77*	50	48	50	--	--	--	--	--	--	--	--
0.88	0.78	0.74	62	55	49	40.6	50.5	52.8	50.9	68.3	65.8	65.6	67.5
0.88*	0.78*	0.74*	65	58	51	--	--	--	--	--	--	--	--

3



LOCATION OF TEST AREAS

PLATE 1

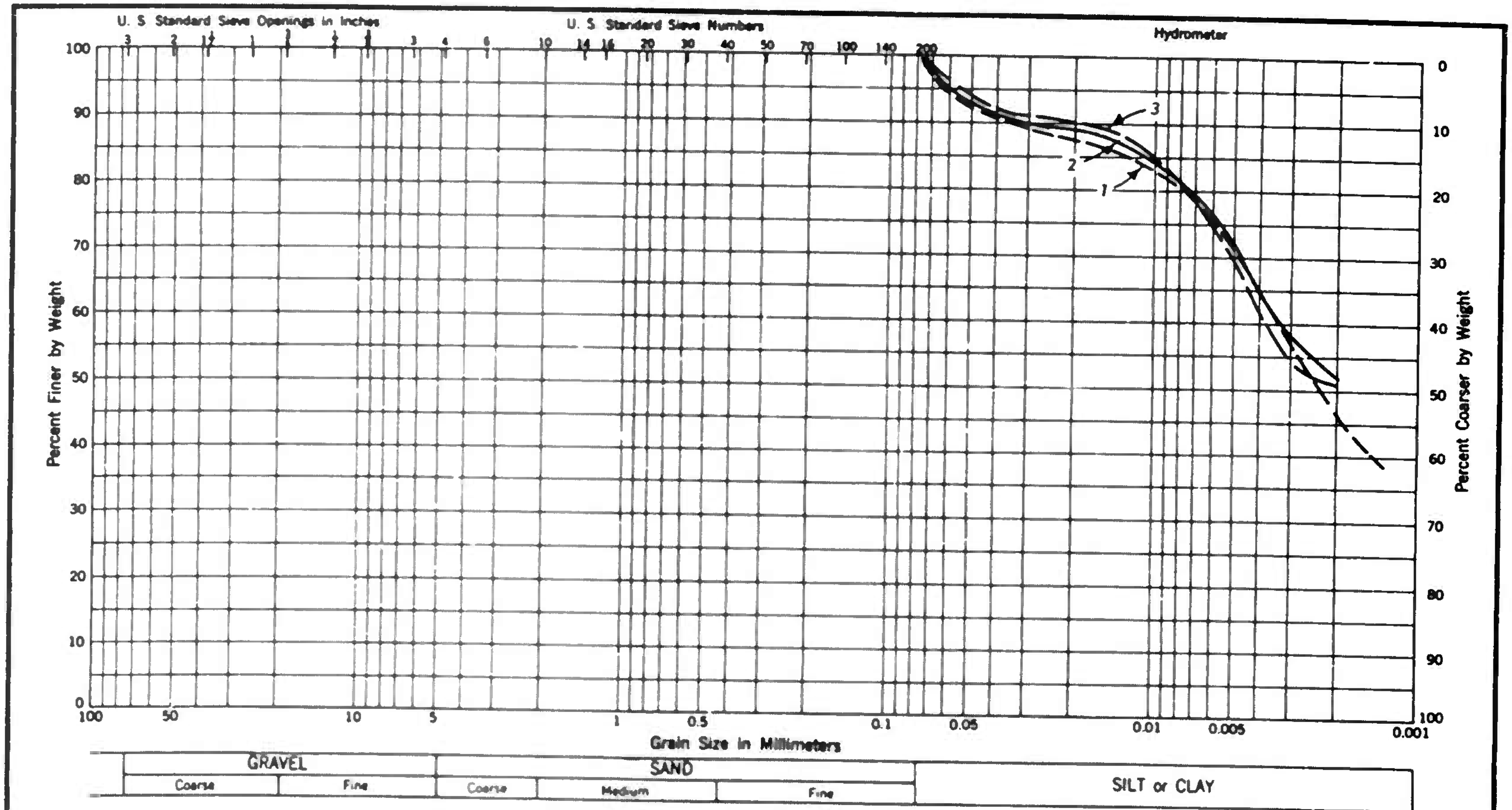


Number	Depth	Natural Moisture	L L	P. L	P. I.	Classification
1	0"-6"					UNIFORM SAND (SP)
2	6"-12"					UNIFORM SAND (SP)

GRADATION AND CLASSIFICATION DATA

MISSISSIPPI RIVER BEACH SAND

PLATE 2

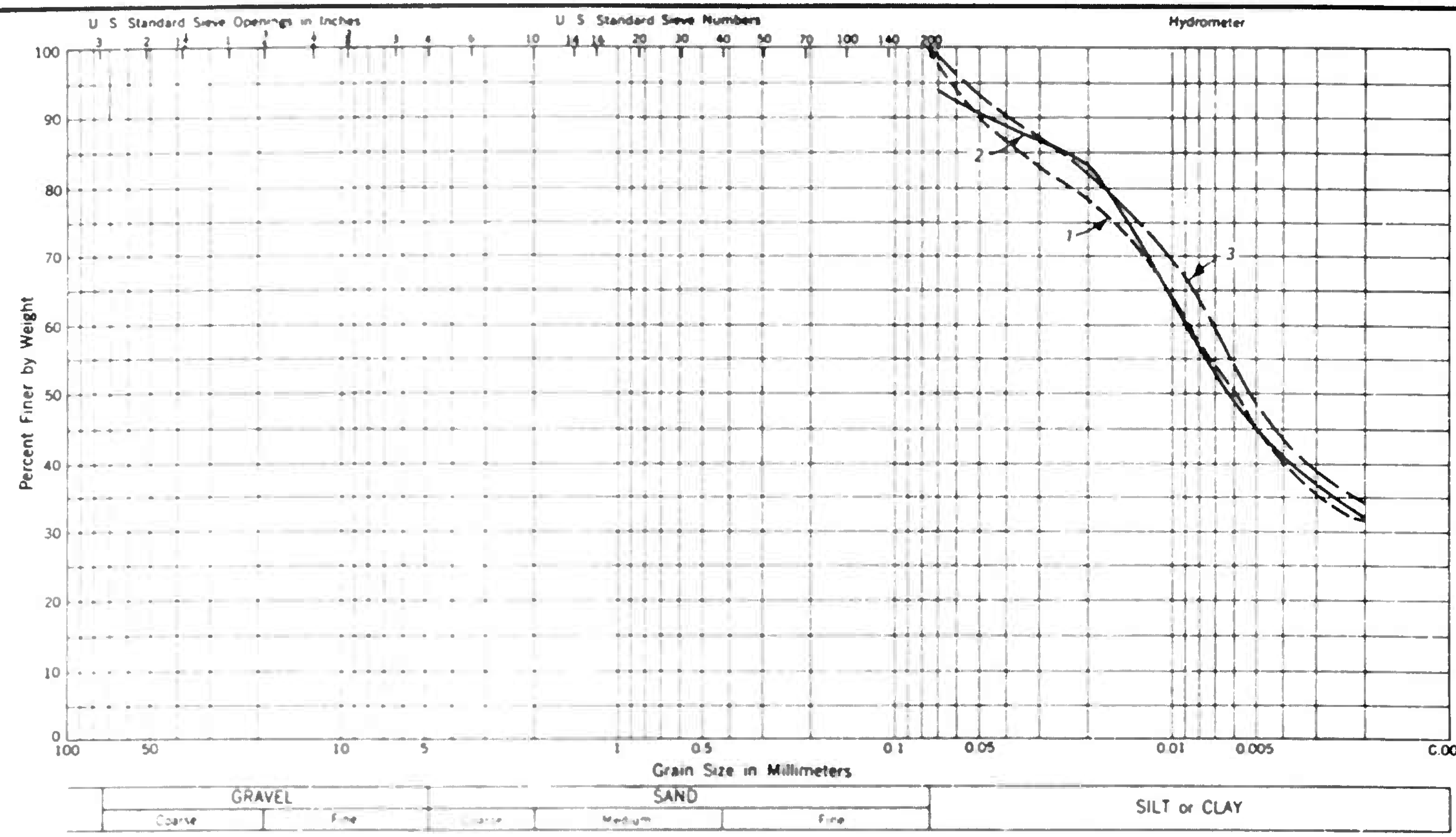


Number	Depth	Natural Moisture	L. L.	P. L.	P. I.	Classification
1	0"-6"		92	34	58	FAT CLAY (CH)
2	6"-12"		87	32	55	FAT CLAY (CH)
3	12"-18"		87	32	55	FAT CLAY (CH)

GRADATION AND SUPPLEMENTARY DATA

ALBEMARLE LAKE SOIL

PLATE 3

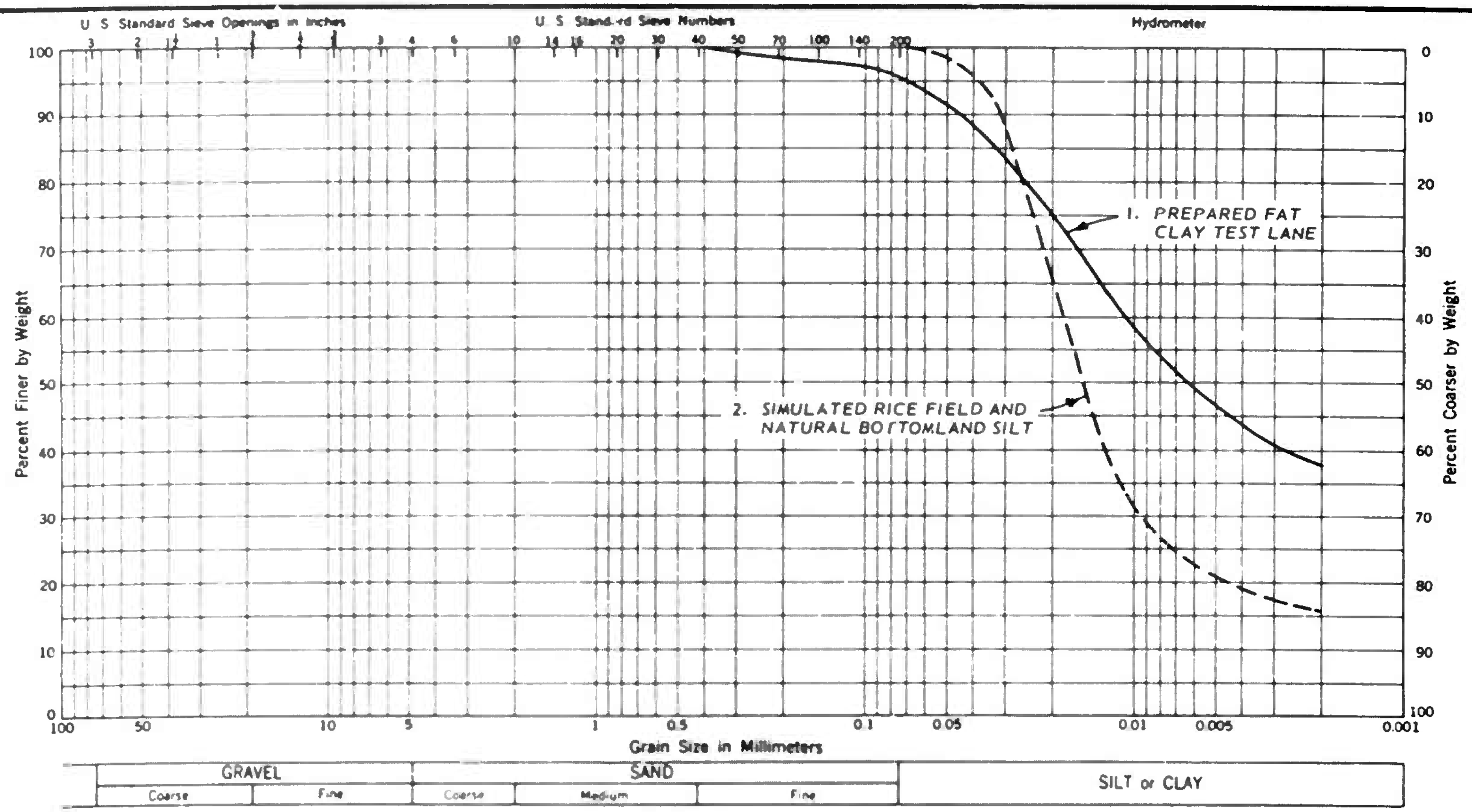


Number	Depth	Natural Moisture	L L	P L	P I	Classification
1	0 - 6		75	28	47	FAT CLAY (CH)
2	6 - 12		81	29	52	FAT CLAY (CH)
3	12 - 18		80	28	52	FAT CLAY (CH)

GRADATION AND SUPPLEMENTARY DATA

CENTENNIAL LAKE SOIL

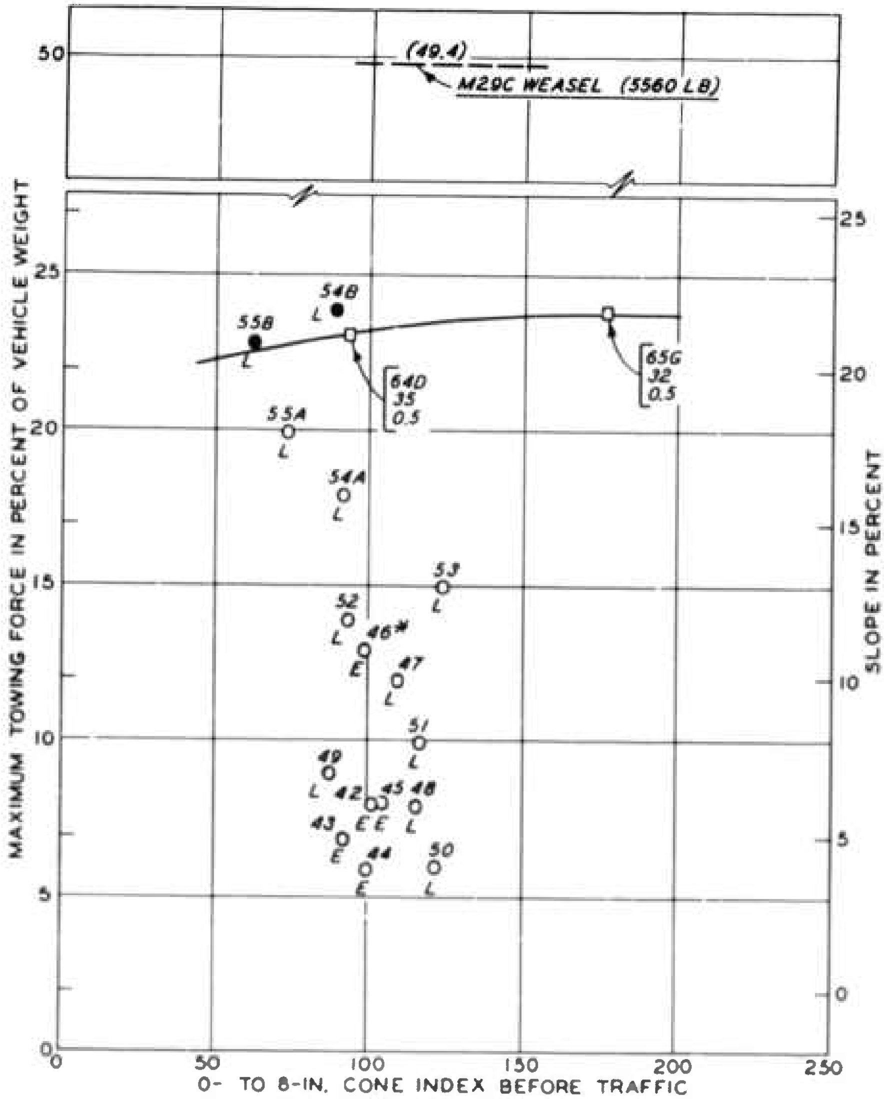
PLATE 4



Number	Depth	Natural Moisture	L L	P L	P I	Classification
1	0"-12"		58	19	39	FAT CLAY (CH)
2	0"-12"		40	27	13	SILT (ML)

GRADATION AND SUPPLEMENTARY DATA

SOILS IN WES TEST AREAS



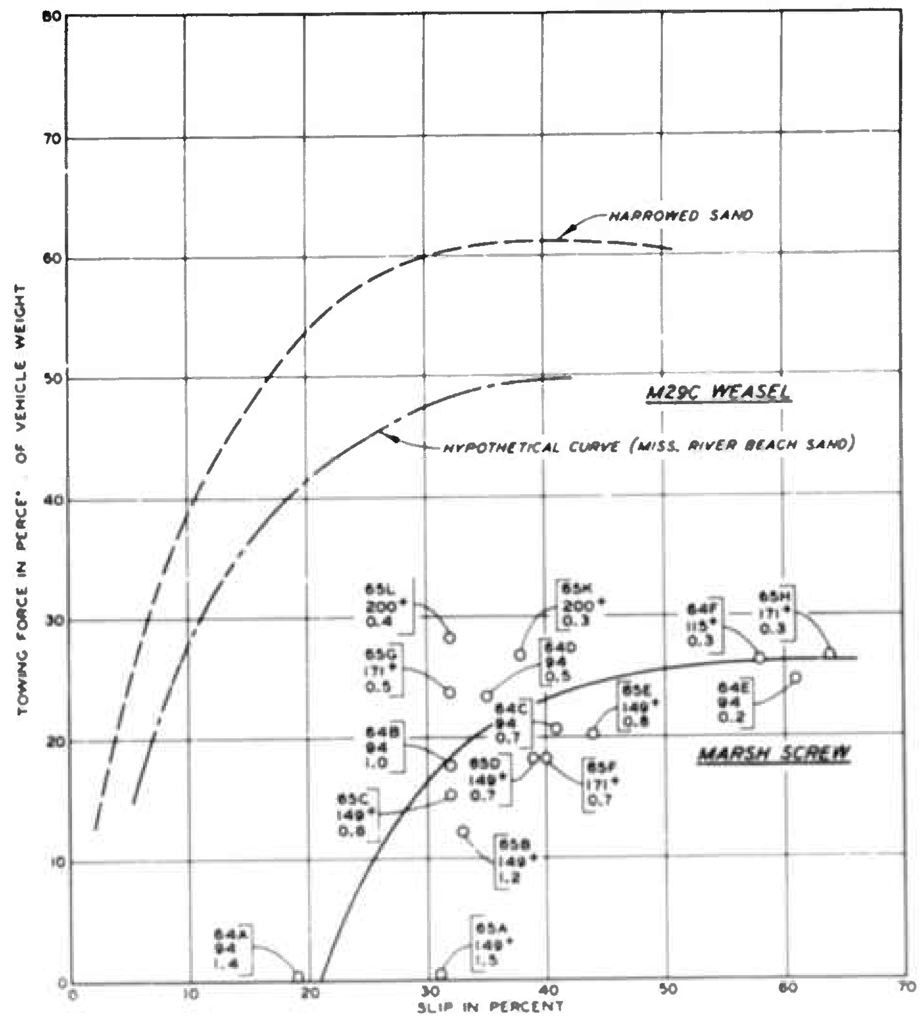
LEGEND

- ● IMMOBILIZED ON SLOPE
- O NOT IMMOBILIZED ON SLOPE
- □ MAXIMUM TOWING FORCE ON LEVEL SOIL
- ✱ VEHICLE TRAVELED BACKWARD
- L VEHICLE LOADED, 3954 LB
- E VEHICLE EMPTY, 2860 LB
- [TEST NUMBER / PERCENT SLIP / SPEED, MPH

NOTE: NUMBERS ABOVE PLOTTED POINTS ARE TEST NUMBERS OF SLOPE TESTS. DATA POINTS FROM TABLES IC AND ID.

SLOPE-CLIMBING AND MAXIMUM TOWING FORCE TESTS

MARSH SCREW
COARSE-GRAINED SOIL
MISSISSIPPI RIVER BEACH



LEGEND

O MARSH SCREW, 3954 LB

TEST NO.
CONE INDEX
SPEED, MPH

M29C WEASEL, 5970 LB
DATA POINTS FROM TABLE 10
——— FROM TM 3-240, 15TH SUPPLEMENT

TOWING FORCE – SLIP TESTS
MARSH SCREW AND WEASEL
COARSE-GRAINED SOIL
MISSISSIPPI RIVER BEACH

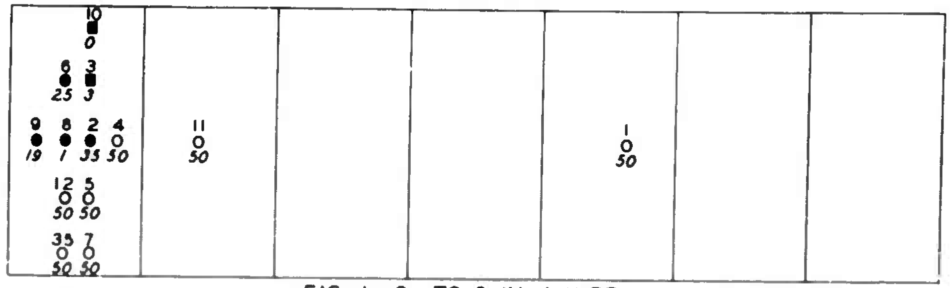


FIG. 1. 0- TO 6-IN. LAYER

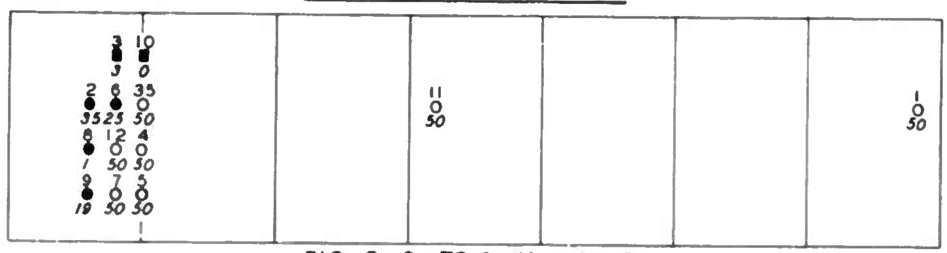


FIG. 2. 3- TO 9-IN. LAYER

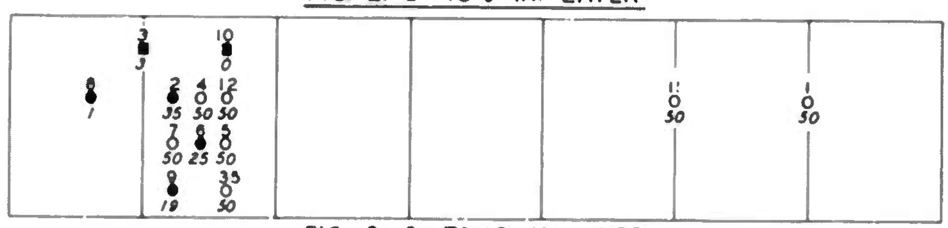


FIG. 3. 6- TO 12-IN. LAYER

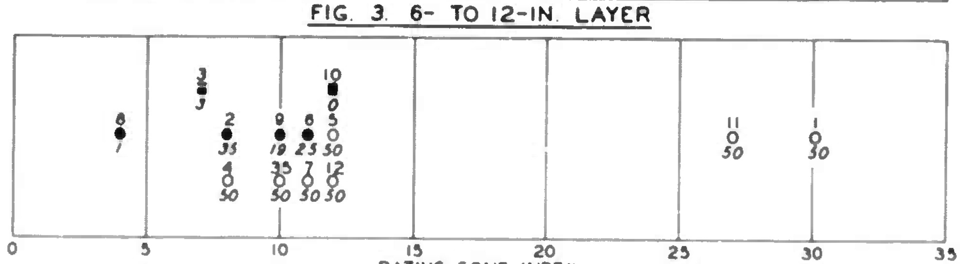


FIG. 4 9- TO 15-IN. LAYER

LEGEND

MARSH SCREW
- O NOT IMMOBILIZED
- ● IMMOBILIZED, ROTORS TURNING

VEHICLE WEIGHT, 3954 LB (EXCEPT TEST 7)
VEHICLE WEIGHT, 2860 LB (TEST 7)

M29C WEASEL
- ■ IMMOBILIZED, TRACKS TURNING

VEHICLE WEIGHT, 4960 LB

NOTE: NUMBERS ABOVE PLOTTED POINTS ARE TEST NUMBERS AND NUMBERS BELOW ARE PASSES COMPLETED.
DATA FROM TABLE 2A

REPETITIVE-PASS TESTS

MARSH SCREW AND WEASEL
FINE-GRAINED SOIL
ALBEMARLE LAKE

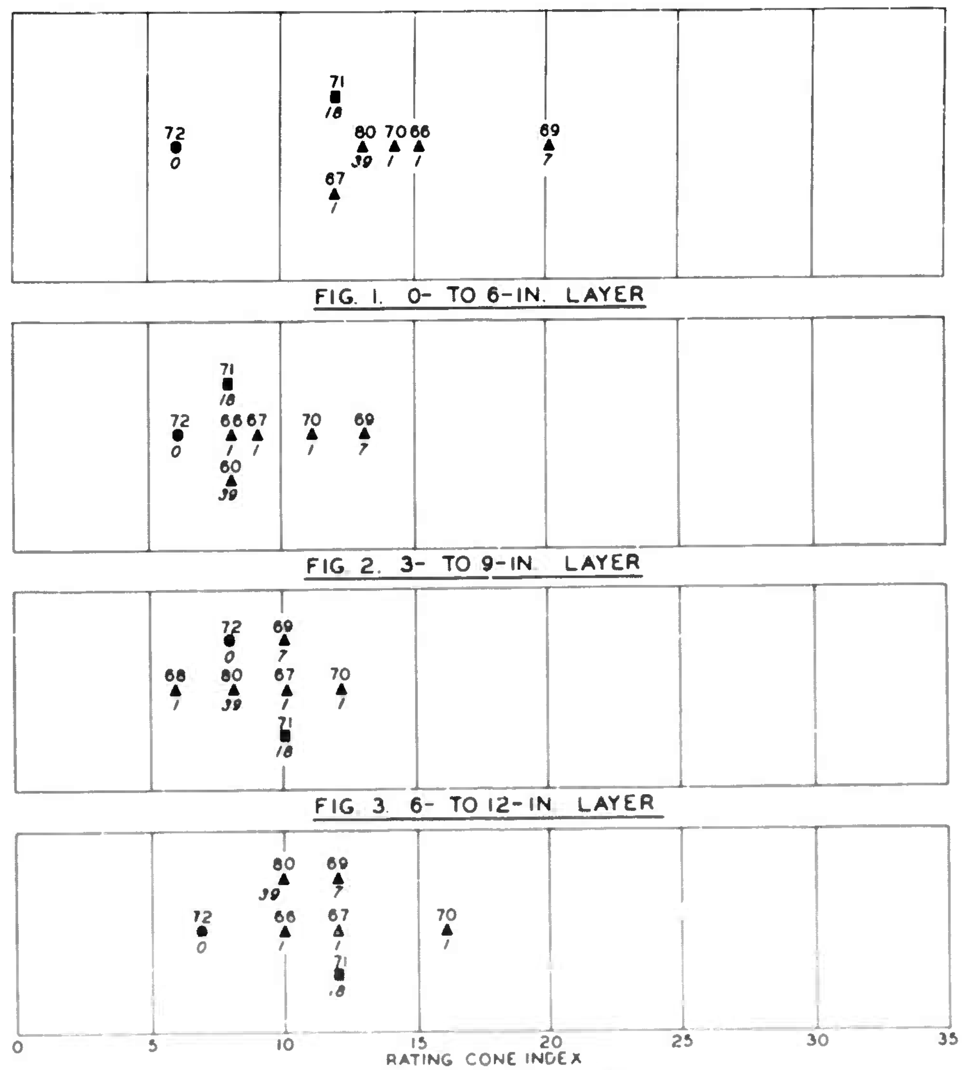


FIG. 4. 9- TO 15-IN. LAYER

LEGEND

MARSH SCREW

▲ IMMOBILIZED, ROTORS NOT TURNING

● IMMOBILIZED, ROTORS TURNING

TEST WEIGHT, 3954 LB (EXCEPT TEST 69)

TEST WEIGHT, 2660 LB (TEST 69)

M29C WEASEL

■ IMMOBILIZED, TRACKS TURNING

TEST WEIGHT, 4960 LB

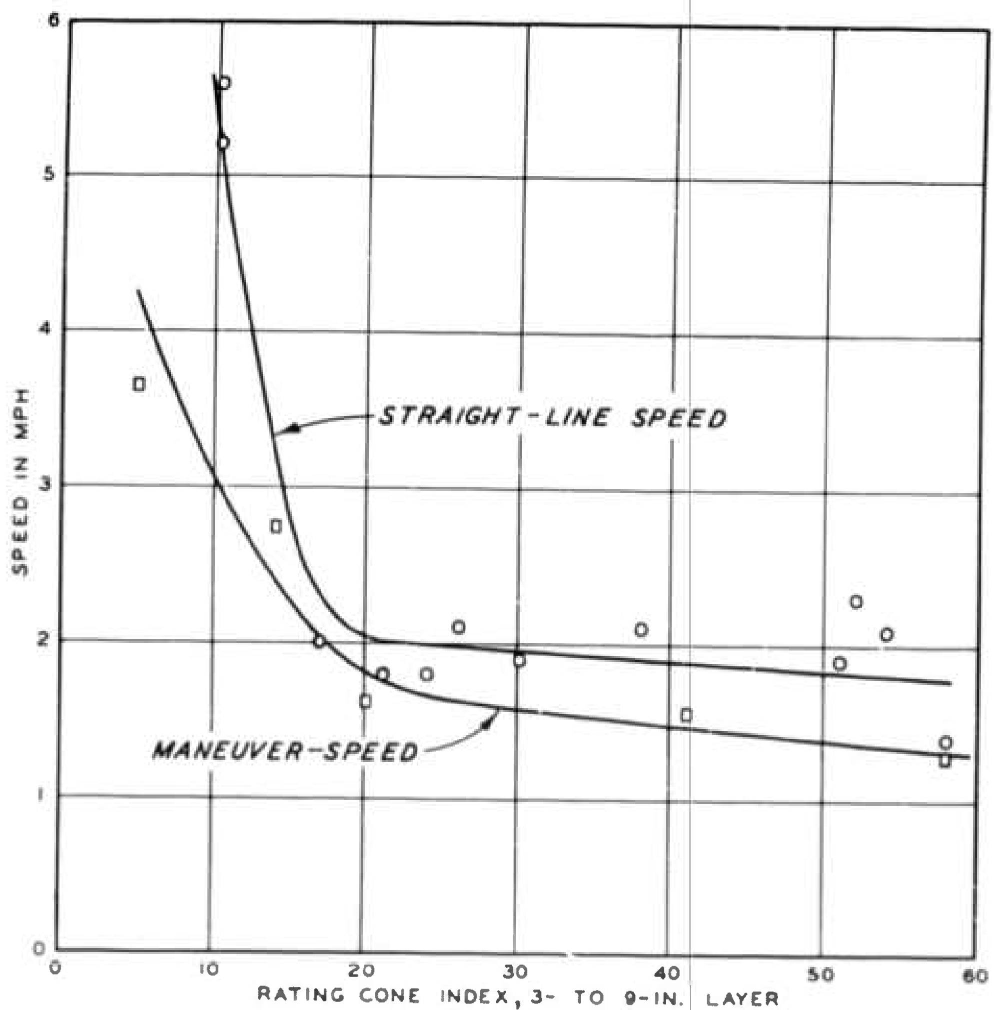
NOTE: NUMBERS ABOVE PLOTTED POINTS ARE TEST NUMBERS AND NUMBERS BELOW ARE PASSES COMPLETED. DATA FROM TABLE 3A.

REPETITIVE - PASS TESTS

MARSH SCREW AND WEASEL

FINE - GRAINED SOIL

CENTENNIAL LAKE



LEGEND

O STRAIGHT-LINE TESTS 98,99, AND 100

□ MANEUVER TEST 101

VEHICLE WT, 3954 LB

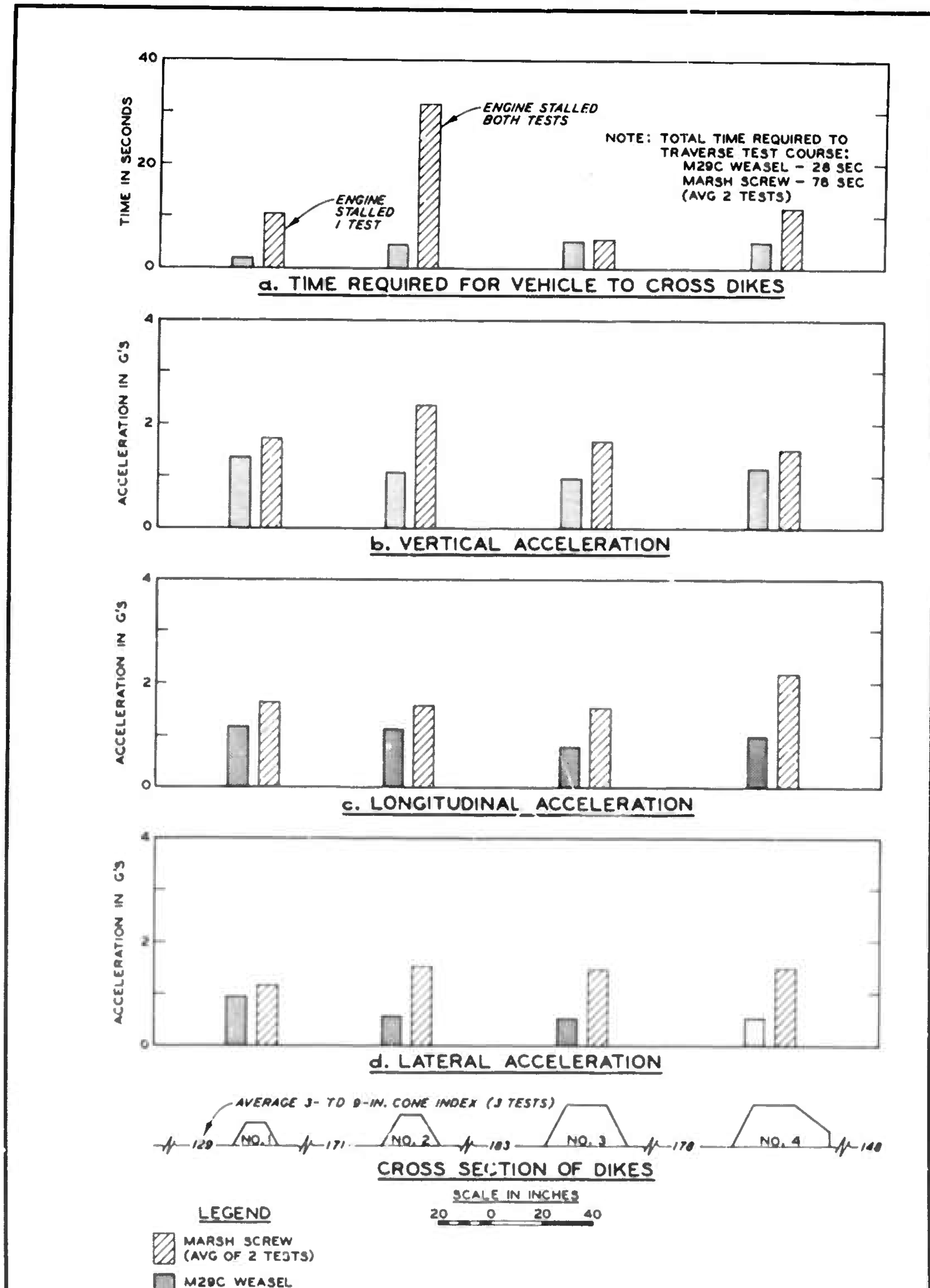
DATA FROM TABLES 2C AND 2D

STRAIGHT-LINE SPEED AND MANEUVER-SPEED TESTS

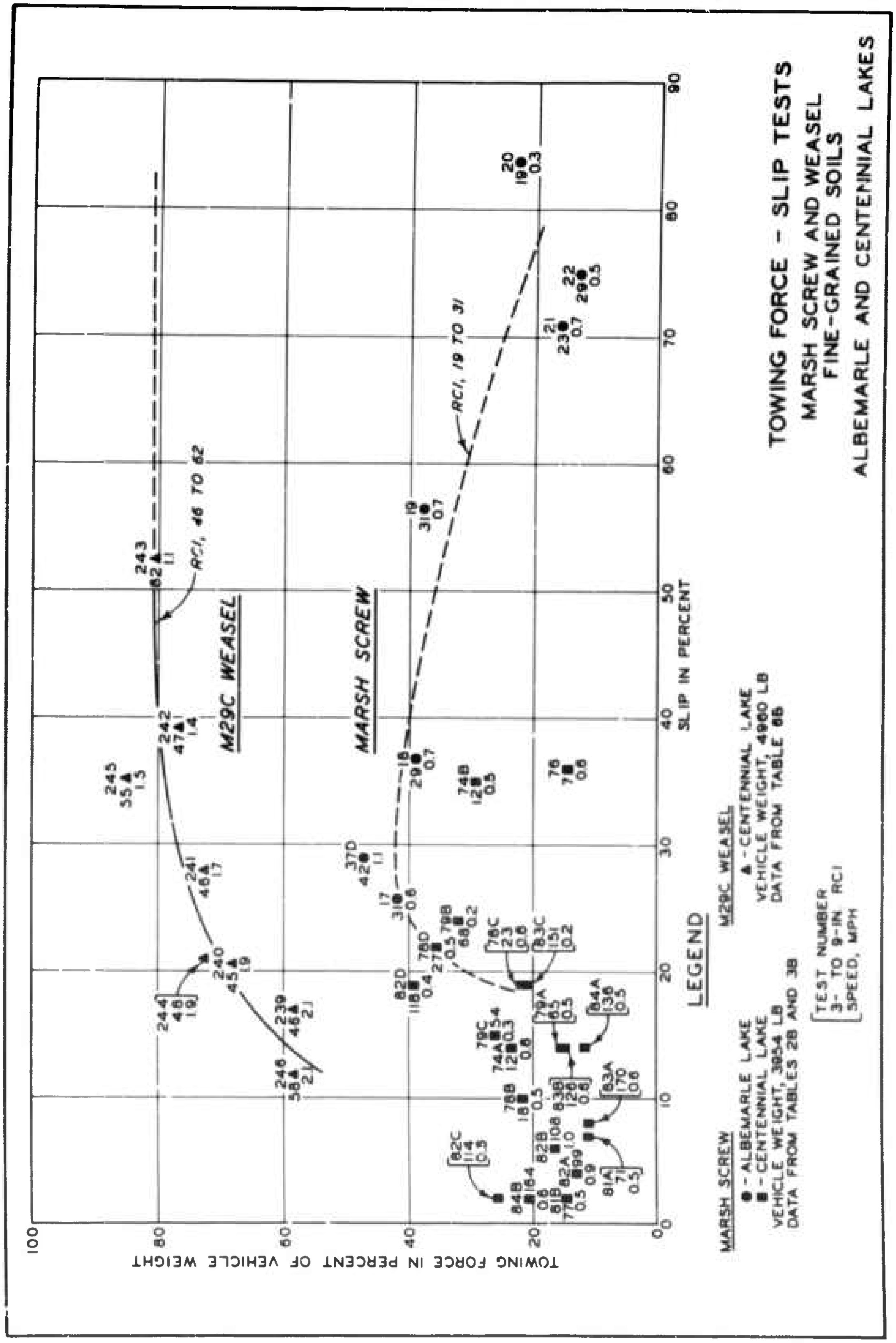
MARSH SCREW

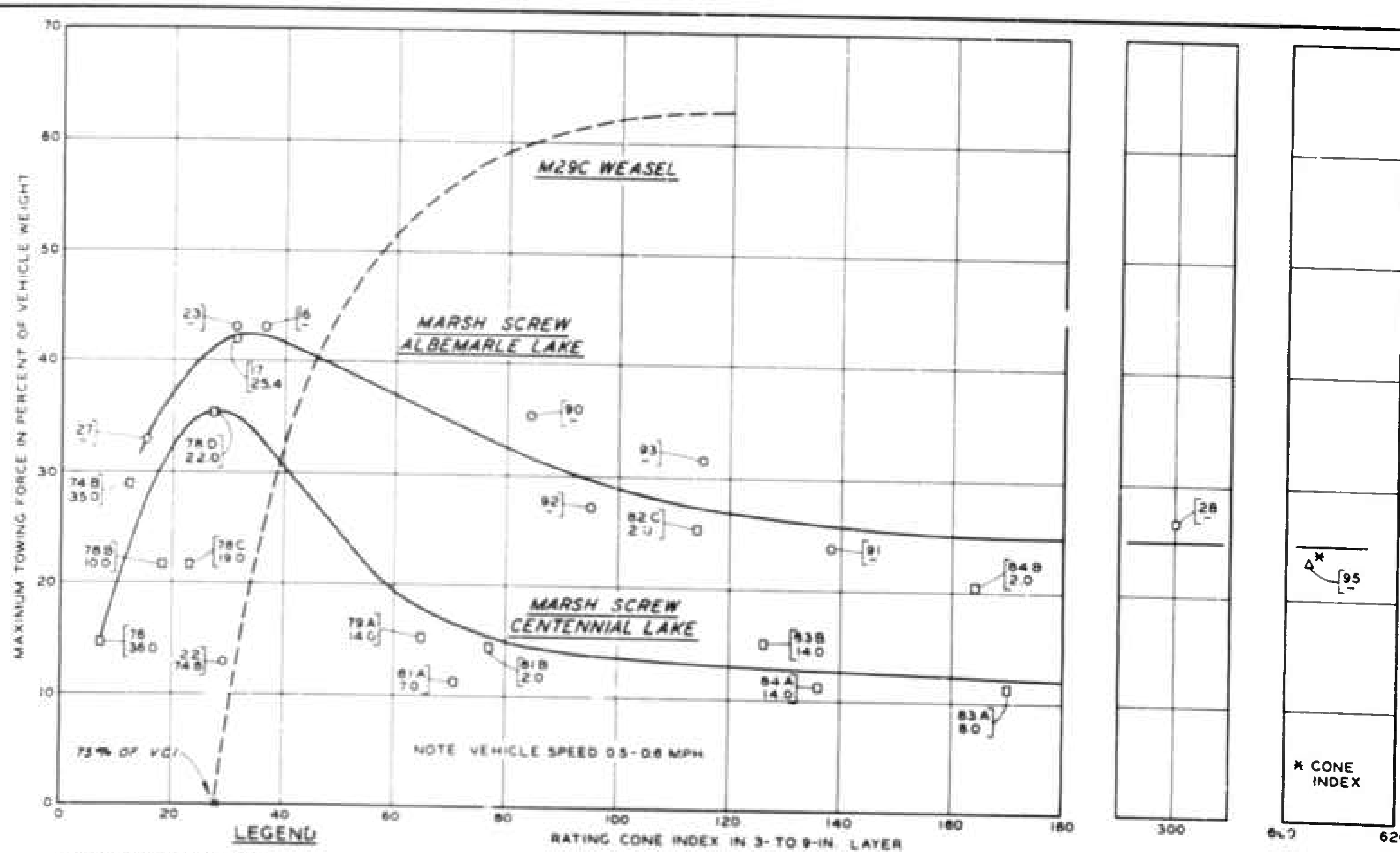
FINE-GRAINED SOILS

ALBEMARLE LAKE



OBSTACLE TESTS
MARSH SCREW AND WEASEL
SIMULATED RICE FIELD


TOWING FORCE - SLIP TESTS
MARSH SCREW AND WEASEL
FINE-GRAINED SOILS
ALBEMARLE AND CENTENNIAL LAKES
TOWING FORCE IN PERCENT OF VEHICLE WEIGHT
SLIP IN PERCENT
M29C WEASEL
MARSH SCREW
RCI, 46 TO 62
RCI, 19 TO 31
LEGEND
MARSH SCREW
● - ALBEMARLE LAKE
■ - CENTENNIAL LAKE
VEHICLE WEIGHT, 3954 LB
DATA FROM TABLES 2B AND 3B
M29C WEASEL
▲ - CENTENNIAL LAKE
VEHICLE WEIGHT, 4960 LB
DATA FROM TABLE 6B
TEST NUMBER
3- TO 9-IN RCI
SPEED, MPH



LEGEND

MARSH SCREW, 3954 LB

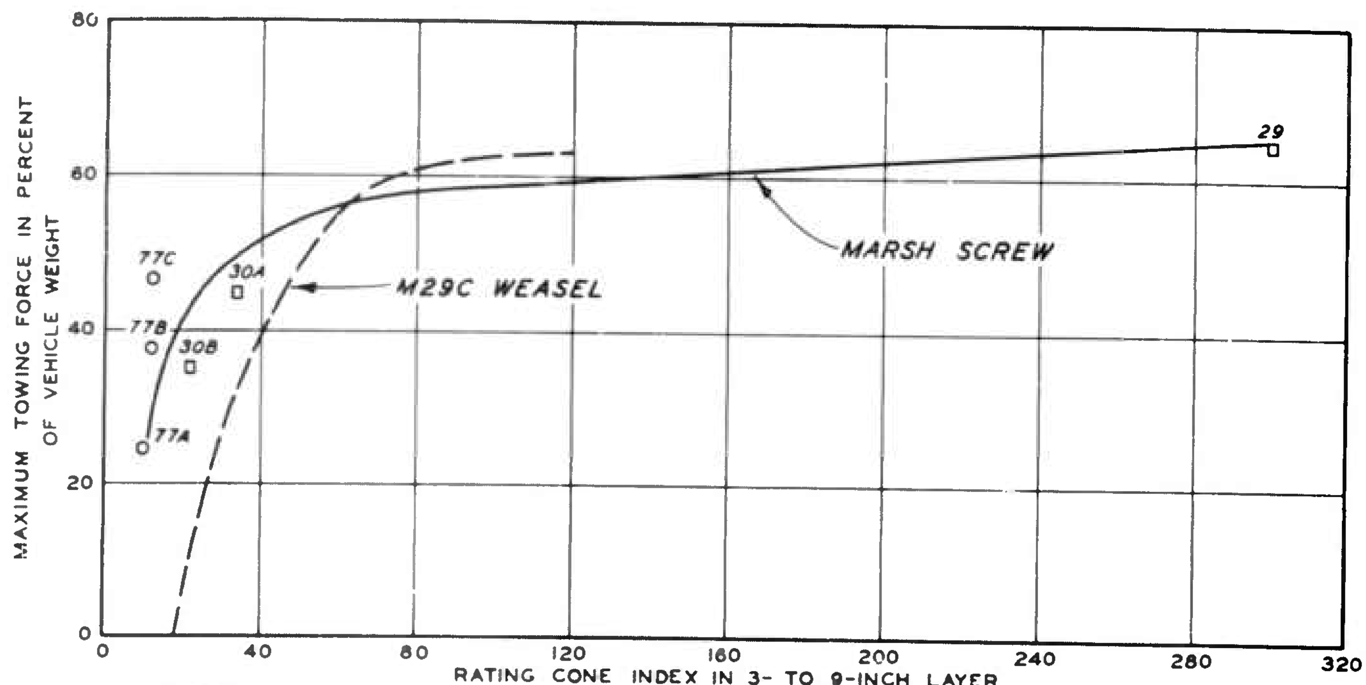
○ ALBEMARLE LAKE TEST FROM TABLE 2B
□ CENTENNIAL LAKE TEST FROM TABLE 3B
△ WES TEST FROM TABLE 4A

M29C WEASEL, 4960 LB, VCI = 24

--- CURVE FROM PLATE 6, TM 3-240, 14TH SUPPLEMENT

[TEST NUMBER
[PERCENT SLIP

MAXIMUM TOWING FORCE TESTS
FORWARD MOVEMENT
MARSH SCREW AND WEASEL
FINE-GRAINED SOILS
ALBEMARLE AND CENTENNIAL LAKES AND WES



LEGEND

MARSH SCREW

- O CENTENNIAL LAKE TESTS
- □ ALBEMARLE LAKE TESTS

VEHICLE WEIGHT, 3954 LB
DATA FROM TABLES 2B AND 3B

M29C WEASEL

— — — PERFORMANCE CURVE FROM 14TH SUPPLEMENT, TM3-240
VEHICLE WEIGHT, 5970 LB

NOTE: NUMBERS ABOVE PLOTTED POINTS ARE TEST NUMBERS.

MAXIMUM TOWING FORCE TESTS
LATERAL MOVEMENT
MARSH SCREW
FINE-GRAINED SOILS
ALBEMARLE AND CENTENNIAL LAKES

PLATE 14

APPENDIX A: DETERMINATION OF VEHICLE CONE INDEX FOR MARSH SCREW AMPHIBIAN

1. The vehicle cone index (VCI) is the minimum soil strength, expressed in terms of rating cone index, that will permit the vehicle to complete 50 passes. It is based on the mobility index (MI) of the vehicle. Computations of the MI's and VCI's at 2860 lb and 3954 lb are described in the following paragraphs.

Mobility Index

2. The MI is a dimensionless number obtained by applying certain vehicle characteristics to the formula given in the following paragraph. Since the Marsh Screw has neither wheels nor tracks, certain assumptions were made; these assumptions are mentioned as necessary.

3. The Marsh Screw is assumed to be operating as a tracked vehicle and the following basic formula for tracked vehicles is used:

$$\text{Mobility index} = \left(\frac{\text{contact pressure factor} \times \text{weight factor}}{\text{track factor} \times \text{grouser factor}} + \text{bogie factor} - \text{clearance factor} \right) \times \text{engine factor} \times \text{transmission factor}$$

wherein

$$\text{contact pressure factor} = \frac{\text{gross wt in lb}}{\text{area of tracks in contact with ground, sq in.}} = \frac{2860 \text{ or } 3954}{2 \times 152 \times 18} = \begin{matrix} 0.52 \text{ at } 2860 \text{ lb*} \\ 0.72 \text{ at } 3954 \text{ lb} \end{matrix}$$

weight factor:
- less than 50,000 lb = 1.0
- 50,000 to 69,999 lb = 1.2
- 70,000 to 99,999 lb = 1.4
- 100,000 lb or greater = 1.8

= 1.0

$$\text{track factor} = \frac{\text{track width in in.}}{100} = \frac{18}{100} = 0.18$$

grouser factor:
- < 1.5 in. high = 1.0
- > 1.5 in. high = 1.1

= 1.1

---

* 3-in. sinkage of rotors assumed; width in contact = 18 in., length in contact = 152 in.

bogie factor $= \dfrac{\text{gross wt} \div 10}{\text{total no. bogies in contact with ground} \times \text{area of 1 track}} = \begin{matrix}0.05 \text{ at } 2860 \text{ lb*} \\ 0.07 \text{ at } 3954 \text{ lb}\end{matrix}$

clearance factor $= \dfrac{\text{clearance in in.}}{10} = \dfrac{20}{10} = 2.0$

engine factor: 10 or greater hp/ton of vehicle wt = 1.00; less than 10 hp/ton of vehicle wt = 1.05 $= 1.00$

transmission factor: hydraulic = 1.00; mechanical = 1.05 $= 1.00$

$$\text{Mobility index} = \left(\frac{\begin{pmatrix}0.72\\0.52\end{pmatrix} \times 1.0}{0.18 \times 1.1} + \begin{matrix}0.05\\0.07\end{matrix} - 2.0 \right) \times 1.0 \times 1.0 = \begin{matrix}0.68 \text{ at } 2860 \text{ lb} \\ 1.70 \text{ at } 3954 \text{ lb}\end{matrix}$$

* Two bogies assumed; area of one track shoe assumed to be same as area of one rotor, i.e. 2736 sq in.

Vehicle Cone Index

4. The VCI is obtained from a curve of MI versus VCI (fig. A1). It can be seen that the Marsh Screw has a VCI of 8 (at 2860 lb) and 11 (at 3954 lb), assuming the vehicle factors mentioned in the preceding paragraph. Since the experimental VCI was determined to be 5 from the tests at Albemarle Lake, it must be recognized that the tracked vehicle formula permits computation of only an approximate value of RCI for the Marsh Screw.

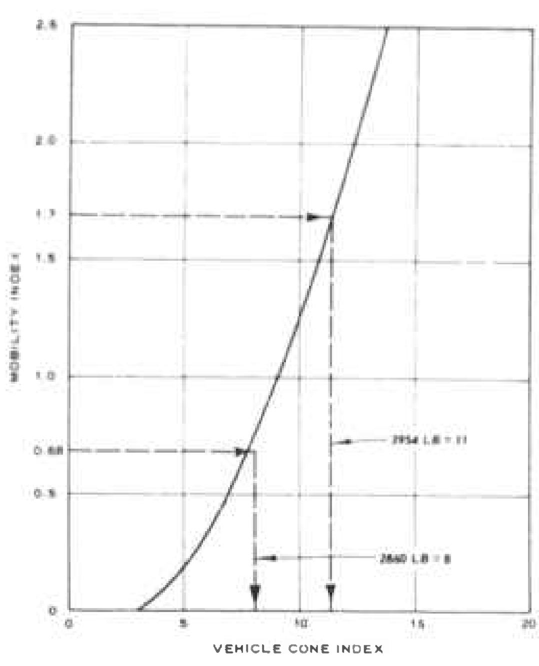


Fig. A1

APPENDIX B: DISCUSSION AND COMPUTATIONS OF THE POWER TRAIN SYSTEM

1. During the field tests it was noted that the Marsh Screw, in certain relatively firm soil conditions, had difficulty propelling itself along at about 1.5 mph because the friction created between rotors and soil would only allow the engine to operate at a maximum of approximately 1500 rpm. During towing tests in the same soil conditions, it was noted that the vehicle could exert considerable pull, but forward movement was reduced to about 0.5 mph.

2. Power is transmitted from the engine through a torque convertor and transmission to a final chain drive connected to each rotor. A schematic flow chart of the power system is shown in fig. B1.

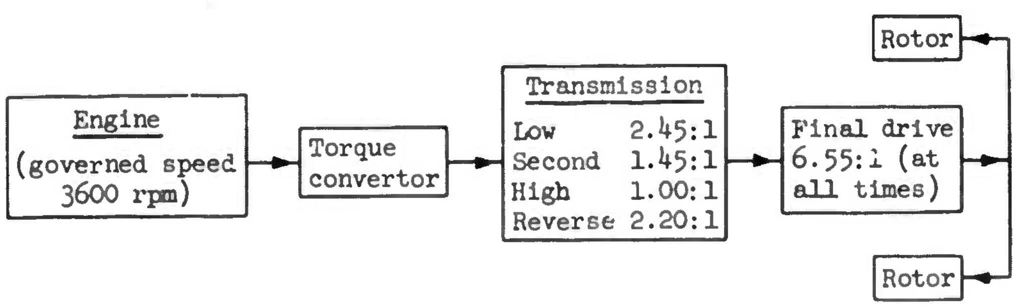


Fig. B1

3. The increased amount of effort at the expense of forward speed (mentioned in paragraph 1 above) may be explained as follows:

a. Assume the engine to be running at full throttle (not necessarily full revolutions per minute). If towing force is applied to the vehicle the torque convertor output in foot-pounds will increase but the torque convertor output in revolutions per minute will decrease; therefore, vehicle speed will decrease. Fig. B2 shows the relations between torque convertor output in foot-pounds and revolutions per minute.

b. When vehicle speed is reduced from 1.5 to 0.5 mph, additional towing force (and horsepower) available may be computed by assuming zero slip of the rotors, zero power loss in the power train, and a constant coefficient of friction between rotors and soil regardless of vehicle speed.

c. For each revolution of the rotors the vehicle moves 4 ft forward; therefore, at 1.5 mph the rotors turn at a rate of 33 rpm, and at 0.5 mph they turn at a rate of only 11 rpm.

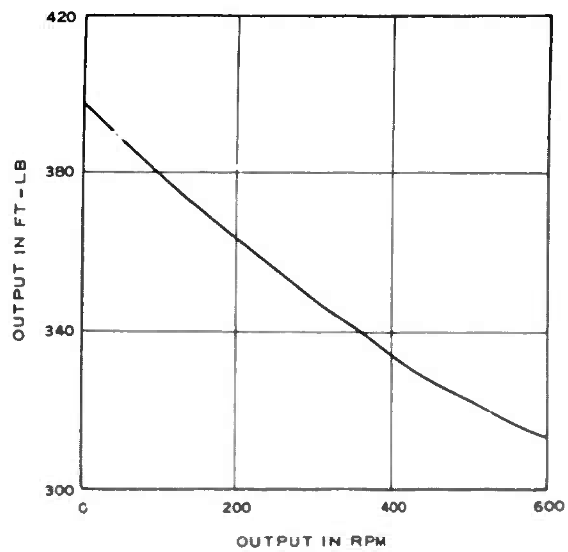


Fig. B2

d. Total reduction from torque convertor output to rotors with transmission in low gear is 16.05:1 (final drive 6.55:1, low gear 2.45:1). When the rotors are turning at 33 rpm (vehicle speed 1.5 mph) the torque convertor output is 529.6 rpm (33 times 16.05), and when the rotors are turning at 11 rpm (vehicle speed 0.5 mph) the torque convertor output is 176.6 rpm (11 times 16.05).

e. From fig. B2, for a torque convertor output of 529.6 rpm, a torque convertor output of 319 ft-lb is obtained, and for a convertor output of 176.6 rpm, a convertor output of 368 ft-lb is obtained. The difference between these torque values (368 and 319) is 49 ft-lb, the amount available for additional towing force when the vehicle speed is reduced from 1.5 to 0.5 mph.

f. The 49 ft-lb of torque at 176.6 rpm is equivalent to 1.6 hp $\left(\text{horsepower} = \dfrac{\text{torque ft-lb} \times \text{rpm}}{5252}\right)$ or 1210 lb of towing force (drawbar pull) at 0.5 mph $\left(\text{drawbar pull} = \dfrac{\text{horsepower} \times 375}{\text{speed, mph}}\right)$:

4. The discussion given above may partially explain why the vehicle was able to tow loads up to approximately 20% of its gross weight at about 0.5 mph, and yet could barely propel itself along at 1.5 mph when towing no load.

U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. TRAFFICABILITY TESTS WITH THE MARSH SCREW AMPHIBIAN ON COARSE-GRAINED AND FINE-GRAINED SOILS, by S. J. Knight, E. S. Rush, and B. G. Stinson. January 1964, vii, 52 pp and 2 appendices - illus - tables. (Technical Report No. 3-641)

Unclassified report

The Marsh Screw Amphibian is of interest in the Army's mobility research program because of its unusual concept of locomotion which is based on the Archimedean screw. It moves by means of two counterrotating rotors which give forward and backward thrust to the vehicle. When both rotors are made to turn in the same direction, the vehicle will move laterally; however, there is no provision for steering when the vehicle is moving laterally. Trafficability tests with the Marsh Screw were performed to determine its performance on three soil types: sand, clay, and silt. Repetitive-pass tests and speed tests were conducted on clay and sand; towing tests on clay, silt, and sand; slope-climbing tests on sand; and obstacle tests on silt. For comparison, tests with an M29C weasel were conducted and performance curves from previous test programs were utilized. Appendix A presents a detailed description of the determination of mobility indexes and vehicle cone index for the Marsh Screw. Appendix B discusses the power train system.

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3. Marsh Screw Amphibian

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